Forest Site Classification in Canada: A Current Perspective

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Forestry Canada
Science and Sustainable Development Directorate
Ottawa, 1992

Forestry Canada Forêts Canada

Canada

Reprinted from The Forestry Chronicle
Volume 68, February 1992, published by the
Canadian Institute of Forestry

©Minister of Supply and Services Canada 1992
Catalogue No. Fo42-174/1992E
ISBN 0-662-19377-6

Copies of this publication may be obtained free of charge from:

Forestry Canada
Public Enquiries Centre
Ottawa, Ontario
K1A 1G5

A microfiche edition of this publication may be purchased from:

Micromedia Ltd.
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Printed on recycled paper

Imprimé sur du papier recyclé

92-04888/

Forest site classification in Canada: A current perspective
Classification des sites forestiers au Canada — perspective actuelle

Introduction

by/par R.A. Sims[1]

Forestry Canada's Forest Site Classification Working Group was founded in 1986. It was to be a forum for federal site classification researchers and others, with regularly scheduled meetings to discuss activities and research interests, share ideas and concerns, and collaborate on group projects. The Working Group acted as the initial catalyst for the preparation of this set of papers.

The Working Group continues to be active. In 1990 its mandate was expanded to include the scientific direction and management of several Forest Land Classification initiatives under the Forestry Canada Science and Technology component of the federal Green Plan. The Group is undertaking a number of nationally oriented projects that include plans for a major conference on forest site classification in 1994, as well as the preparation of training materials on site classification and the completion of publications and reports on several topics. New site classification research will be also be undertaken, some of it affiliated with Model Forests — a major initiative under the Green Plan. Through such venues, the Working Group will attempt to expand the knowledge base on forest site classification in Canada.

The following papers provide nine regional treatments on site classification, preceded by a particularly insightful overview by Stan Rowe. Together, the package offers a snapshot of current site classification activities in various parts of Canada. It is not a complete picture, of course: some provinces are not covered, and there are other site classification activities at stages still too early to report. Moreover there is a wide spectrum of overlap between what is generally discussed in these papers, namely "forest land description, classification and mapping," and various other broad subject areas such as silviculture, phytosociology, soil science, geomorphology, geomatics and remote sensing. This situation makes it very difficult to draw the line on what to include or exclude from a comprehensive treatment of forest site classification.

This collection should serve to stimulate awareness of and interest in the considerable amount of current activity in forest site classification. This set of papers is perhaps especially timely, as a pan-Canadian status report on site classification activities has not been produced since the Conference on Ecological Classification at UBC in 1977. Several recent symposia and researchers have dealt with important site classification issues: Bockheim in 1984 and van Groenewoud in 1986, on general philosophy and methodology; Wickware and Stevens in 1986 and Mengel and Tew in 1991, on applied forest management. None, however, has included the Canadian cross-country update of activities provided here.

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Le groupe de travail de Forêts Canada sur la classification des sites a été fondé en 1986 pour servir de lieu de rencontre régulier entre les spécialistes fédéraux de la recherche sur la classification des sites et d'autres chercheurs, afin qu'ils puissent discuter de leurs activités et de leurs recherches, communiquer leurs idées et leurs points d'intérêt, et collaborer à des projets de groupes. Le groupe de travail a été le point de départ de la présente série d'articles.

Le groupe de travail poursuit ses activités et a vu son mandat s'élargir en 1990 pour inclure la direction scientifique et la gestion de plusieurs projets de classification des terres forestières; ce travail représente l'apport scientifique et technologique de Forêts Canada au Plan vert du gouvernement fédéral. Le groupe de travail entreprend un certain nombre de projets d'envergure nationale qui comprennent la préparation d'une importante conférence sur la classification des sites forestiers en 1994, ainsi que la création de matériel de formation sur la classification des sites, de publications et de rapports sur divers sujets. De nouvelles recherches sur la classification des sites seront également entreprises, en partie dans le cadre des forêts modèles, une des grandes initiatives du Plan vert. Le groupe de travail s'efforce ainsi d'augmenter notre connaissance en matière de classification des sites forestiers au Canada.

Les articles qui suivent représentent neuf perspectives régionales de la classification des sites. Ils sont précédés d'un avant-propos particulièrement probant de Stan Rowe. Dans leur ensemble, ces articles offrent un coup d'œil des opérations de classification des sites pratiquées actuellement dans diverses régions du Canada. Il ne s'agit pas d'une image complète, bien sûr, puisque certaines provinces ne sont pas mentionnées; tandis que d'autres opérations de classification ne sont pas à un stade assez avancé pour être rapportées. Il faut ajouter que les sujets abordés dans ces articles, soit la description des terres forestières, la classification et la cartographie, recouvrent en partie d'autres domaines généraux comme la sylviculture, la phytosociologie, la science des sols, la géomorphologie, la géomatique et la télédétection. Il est donc très difficile de fixer les limites d'une classification des sites forestiers qui soit complète.

La lecture de ces articles permettra non seulement de découvrir l'étendue des activités qui se rapportent à la classification des sites forestiers, mais elle pourrait également susciter un intérêt plus vif envers ce sujet. Alors, cette publication arrive peut-être au bon moment puisque l'on n'a pas produit de rapport d'étape sur la classification des sites forestiers à l'échelle du Canada depuis la conférence sur la classification écologique tenue à l'université de Colombie-

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As Burger and Pierpoint aptly noted in 1990, classification is only a means to an end: the usefulness of site classifications as forest management tools ultimately lies in *how* they are implemented, applied and built upon. Certainly, it is clear from this set of papers that the current, quantitatively based site classification systems, are beginning to occupy important new roles in operational forest management across Canada. Undoubtedly, their use will increase in the future.

It is also clear that different parts of the country are at different stages in the implementation and development of forest site classification systems, and that philosophies and approaches have varied. As Rowe points out in his prologue to these papers, this is not of particular concern or consequence. There is, however, a need for the development of certain "equivalences" of terminologies to draw together the common threads that do exist. Forestry Canada's Forest Site Classification Working Group will continue to play a role in these activities over the coming years.

In conclusion, I should mention that the papers in this collection were not subjected to the *Forestry Chronicle*'s standard review process; rather, prior to their submission, the papers underwent a formal peer review and edit by members of the Working Group and others. To those that assisted in this process, I extend my sincere thanks.

Britannique en 1977. Récemment, plusieurs colloques et chercheurs ont traité d'importantes questions portant sur la classification des sites, telles les concepts, l'attitude générale et la méthodologie (Bockheim en 1984, et van Groenewoud en 1986), et l'aménagement appliqué des forêts (Wickware et Stevens en 1986, et Mengel et Tew en 1991). Cependant, aucun d'eux n'a présenté une mise à jour des activités à l'échelle du Canada comme celle que l'on obtient ici.

Comme Burger et Pierpoint (1990) l'ont si bien remarqué en 1990, la classification n'est qu'un outil. Son utilité dans l'aménagement des forêts est déterminée, en dernier ressort, par la façon dont elle est mise en œuvre, appliquée et développée. Il apparaît très clairement dans ces articles que les systèmes quantitatifs actuels de classification des sites commencent à jouer de nouveaux rôles importants dans l'aménagement opérationnel des forêts au Canada, tendance qui ne pourra sans doute que s'accentuer dans l'avenir.

En outre, il ressort clairement que les étapes de mise en œuvre et de développement de systèmes de classification des sites forestiers varient de région en région à travers le pays, et que les attitudes générales et les méthodes utilisées varient également. Mais comme S. Rowe l'indique dans son avant-propos, cela ne pose pas de problème particulier. Cependant, le besoin se fait sentir d'«équivalences» dans la terminologie afin de rapprocher les éléments communs qui existent déjà. Le groupe de travail sur la classification des sites forestiers de Forêts Canada continuera à œuvrer en ce sens à l'avenir.

Finalement, il faudrait mentionner que les articles de cette publication n'ont pas été l'objet du processus habituel de révision de *The Forestry Chronicle*; ce sont les membres du groupe de travail et d'autres spécialistes qui ont entrepris la révision et la correction des articles, avant de les soumettre. Je tiens à remercier sincèrement tous ceux qui ont participé à cet effort.

Prologue/Avant-propos

by/par J. Stan Rowe[1]

Forestry in Canada has a 65-year tradition of site classification whose beginning in the late 1920s is associated with the visit to North America of Ilvessalo, a student of Cajander, the Finnish ecologist. The discovery was made that in the simply structured boreal forests of Fenno-Scandia and Canada the minor vegetation showed a close correlation with soil moisture-nutrient regimes — a vital clue to the potential productivity of the spruce, pine, birch and poplar overstory. For thirty years "site classification" meant identification of indicator plant communities, and foresters were encouraged to know their plants by such justly famous people as Brinkman, Halliday, Heimburger, Rousseau, Lafond, Linteau, Ray, Lossee, Sisam and Spilsbury.

This phytosociological phase began to wane in the 1950s and 1960s with the appearance in Ontario forests of a soil surveyor, Angus Hills, who more than anyone else turned the attention of research foresters to the previously unseen substratum in which trees and minor vegetation are rooted. Stressing the importance of physiography, Hills and his students eventually developed a total site or ecosystem approach

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La classification des sites forestiers au Canada a commencé il y a soixante-cinq ans. Ses débuts correspondent à la visite, à la fin des années 1920, d'Ilvessalo, étudiant de l'écologiste finnois Cajander. On a découvert que dans les forêts boréales finno-scandinaves et canadiennes aux structures très simples, la menue végétation était étroitement liée à l'humidité et aux éléments nutritifs du sol, ce qui laissait supposer le potentiel productif de l'épinette, du pin, du bouleau et du peuplier. Pendant trente ans, la «classification des sites» était synonyme d'identification des communautés végétales indicatrices, et des gens aussi célèbres que Brinkman, Halliday, Heimburger, Rousseau, Lafond, Linteau, Ray, Lossee, Sisam et Spilsbury encourageaient les forestiers à «connaître leurs plantes».

Cette phase phytosociologique a commencé son déclin dans les années 1950 et 1960 avec l'arrivée dans les forêts ontariennes du topographe Angus Hill. C'est lui qui, plus que tout autre, a attiré l'attention des chercheurs forestiers sur le sous-sol, jusque-là «inexistant», dans lequel les arbres et la menue végétation prennent racine. En mettant l'accent

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to the appraisal of lanscapes integrating climate, vegetation and soil on the landform base. The belief that geomorphology — landform, its composition and structure — is genetic for landscape ecosystems through its influence on local climate, drainage, soil formation and the recruitment of plants and animals — was new and radical, though today it is the indispensable foundation of terrain analysis world-wide. During the same period in British Columbia the phytosociological appraisal of forest sites remained strong, though reformed by Krajina and his students to a more inclusive biogeoclimatic approach that also takes account of climate, soils and topography.

The period from 1970 to the early 1980s was a time of forest land assessment and terrain analysis, encouraged by such programs as the Canadian Land Inventory and environmental assessments of proposed mega-developments in the north. Half-a-dozen inclusive systems for forest site mapping and classification were devised regionally, by researchers like Damman in Newfoundland, Jurdant in Quebec and Mueller-Dombois in Manitoba. Though differing in particulars, they were not fundamentally unlike the procedures of Hills in Ontario or Krajina in British Columbia, and their influences remain strong. In the late 1970s an attempt was made to systematize terminology and procedures in the provinces and territories through the Canadian Committee on Ecological (Biophysical) Land Classification, but without marked success. Those who seek a broad understanding of the ecology of forest land across this country must still struggle with half-a-dozen different jargons.

Latest on the scene are the methods exemplified in this volume of *The Forestry Chronicle*, marked by a continuing effort to bring together the most important indicators of the potential of forest lands, utilizing computer-based multivariate mathematical techniques. Every generation must discover reality for itself and a new vigorous cohort of research workers is again tilling the well-ploughed field. The nine papers that follow are concerned with the perennial problem of simplifying and making sense of the tremendous variability that characterizes Canada's forested lands. That variability is to some extent responsible for the different approaches and terminologies which characterize regional programs, and is reflected in their titles: Forest Site Classification, Forest Management Site Classification, Forest Ecological Classification, Ecological Land Survey and Biogeoclimatic Ecosystem Classification. The common focus, nevertheless, is on place, on geographic area, on *site*: the stage where each unique complex of climate-biota-soil-landform carries on its dynamic and ever-changing performance, directed and invigorated by solar energy.

In reading these papers, two valid and complementary approaches to the study of forestland sites need to be differentiated. The first is the practice of partitioning the land into more or less homogeneous units by *mapping* landscapes; the second is the logical *grouping* of land units, however derived. Geographers call the first "regionalization" or survey (as in soil survey) and the second "classification." Regionalization is "from above," proceeding analytically by division and subdivision, with an eye for differences, usually relying on aerial imagery. Classification is "from below," proceeding synthetically by aggregation, with an eye on similarities, relying on taxonomic concepts. The two sometimes go together, but not always. Therefore, calling both "site classification" — a common error in the forestry literature — is a source of confusion.

sur la physiographie, Hills et ses étudiants en sont venus à mettre au point une méthodologie fondée sur le site dans sa globalité, ou écosystème, permettant d'évaluer les paysages en intégrant le climat, la végétation et le sol au type de relief. L'idée que la géomorphologie — le terrain, sa composition et sa structure — puisse être génétique des écosystèmes paysagers par son influence sur le climat local, l'hydrographie, la formation des sols, les plantes et les animaux, était une idée nouvelle et radicale qui, aujourd'hui, est à la base des analyses de terrain dans le monde entier. À la même époque, en Colombie-Britannique, Krajina et ses étudiants ont conservé la méthode phytosociologique en l'adaptant pour en faire une méthode biogéoclimatique plus globale tenant compte également du climat, des sols et de la topographie.

Entre 1970 et le début des années 1980, on a effectué des évaluations des terres forestières et des analyses de terrain, dans le cadre de programmes tels que l'Inventaire des terres canadiennes, et d'évaluations environnementales de grands projets de développement dans le Nord. Environ six systèmes globaux de cartographie et de classification des sites forestiers ont été créés régionalement, tels ceux de Damman à Terre-Neuve, Jurdant au Québec et Mueller-Dombois au Manitoba. Bien que différents dans le détail, ces systèmes n'étaient pas foncièrement distincts des procédés de Hills en Ontario ou de Krajina en Colombie-Britannique; mais leur influence se fait toujours sentir. À la fin des années 1970, on a tenté, sans grand succès, de systématiser la terminologie et les procédés dans les provinces et les territoires avec le Comité canadien sur la classification écologique (biophysique). Aujourd'hui encore, il faut s'attaquer à une demi-douzaine de jargons pour avoir une vue de l'écologie forestière canadienne dans son ensemble.

Cette publication-ci se fonde sur les méthodes les plus récentes qui s'efforcent d'associer les principaux indicateurs du potentiel des terres forestières, en utilisant des techniques mathématiques informatisées à variables multiples. Chaque génération se doit de découvrir la réalité à sa façon. C'est pourquoi un autre groupe de chercheurs décidés vient à son tour travailler le terrain. Les neuf articles qui suivent portent sur l'éternel problème de simplifier et de chercher à comprendre l'immense variabilité caractéristique des forêts canadiennes. Cette variabilité explique jusqu'à un certain point les différences entre les méthodes et la terminologie qui caractérisent les programmes régionaux, comme cela ressort dans les titres : classification des sites forestiers, classification des sites d'aménagement forestier, classification écologique des forêts, inventaire écologique du territoire, et la classification biogéoclimatique des ecosystems. Le point commun reste tout de même le lieu, la région géographique, le *site* où chaque complexe unique formé par le climat, le biote, le sol et le relief évolue, dans un dynamisme perpétuel, grâce à la vigueur de l'énergie solaire.

En lisant ces articles, on doit faire la différence entre deux procédés valides et complémentaires de l'étude des sites forestiers. Le premier consiste à découper le terrain en zones plus ou moins homogènes que l'on représente sur une carte de la région; le deuxième regroupe de façon logique des zones forestières obtenues de diverses manières. Les géographes appellent le premier procédé «régionalisation» ou relevé (comme dans l'expression relevé pédologique), et le deuxième «classification». La régionalisation vient «d'en haut», et procède de façon analytique par divisions et subdivisions, en cherchant les différences et normalement en se servant de représentations aériennes. La classification, fondée sur

Readers will note that the accent in the Quebec studies as reported here is on regionalization or mapping, an expensive procedure when conducted on a large scale over large areas. In most other provinces — not entirely because of economic constraints — the accent is on classification systems from data gathered on sample plots (exemplified in field guides), with mapping a secondary consideration. The Manitoba report points out that most practical users prefer site information in the form of regionalization because of familiarity with maps, although silviculturists prefer site-specific information which can be communicated efficiently in tabular or written form. The conclusion, and I believe it is the right one, is that we need both regionalizing and classifying, mapping and field guides, the landscape view and the site-specific view. Which should lead, other things being equal? My bias is revealed by the order in which the pairs are listed.

"Ecosystem" is another potential pitfall. Confusion in its use arises from two views enmeshed in the same term. Some conceive forestland ecosystems as built up additively from below, comprising essentially vegetation and soil. Others, adopting a top-down view, conceive forestland ecosystems as whole landscapes which comprise everything that earth-space contains: landform-soil-biota-atmosphere. Thus an ecosystem approach can mean either taking something more than vegetation into account (adding to it soil, wildlife, water, etc.) or dealing with three-dimensional landscapes and everything in them.

What is perhaps most novel and challenging for the forest ecologist today, is the re-conception of forest land as a provisioner of many commodities and values: water, animal and plant wildlife, recreation and aesthetics, as well as lumber and fiber. To understand each tract of land, each forest site, in its regional context is the only possible basis for sustained use. The aim is therefore to understand forested ecosystems regionally and locally, identifying their "capital" that *must be maintained* if periodic "interest" is to be drawn off in the form of water, animals, plants and aesthetic enjoyment. This approach will be the touchstone for forest site assessments in the future. The ultimate value of these papers is their contribution to that end.

In the above context an interesting question is who uses and will use the results of forest site assessments? Several papers make the point that the needs of users should be solicited before beginning the work in the office and in the field. The up-side of such a procedure is that the results are likely to be relevant to those who were consulted. The down-side is the likelihood that a large sector of society is left out. To the extent that research ecologists have a free hand, they should perhaps spend more time consulting among themselves as to what society's needs are likely to be, thus counterbalancing the more insistent traditional needs.

des notions taxonomique vient «d'en bas» et procède synthétiquement en rassemblant, et en cherchant les similarités. Les deux procédés vont parfois de pair, mais pas toujours. L'erreur commune dans les écrits sur la foresterie, qui consiste à appeler ces deux procédés «classification des sites», prête à confusion.

Le lecteur remarquera que les études faites au Québec, que nous rapportons ici, s'appuient sur la régionalisation ou la cartographie, procédé dispendieux s'il est effectué à grande échelle. Dans la plupart des autres provinces, et pas seulement pour des raisons d'économie, on préfère les systèmes de classification de données recueillies sur des parcelles-échantillons (illustrées dans les guides du terrain); la cartographie est alors reléguée au second plan. Le rapport du Manitoba indique que la plupart des utilisateurs préfèrent que l'information soit présentée selon la méthode de régionalisation, car ils sont à l'aise avec des cartes. Les sylviculteurs, quant à eux, trouvent plus efficace que l'on communique l'information par station, sous forme écrite ou dans une table. En conclusion, je crois que l'on peut dire que nous avons besoin et de la régionalisation et de la classification, et de la cartographie et des guides de terrain, et de la vision globale et de la vision spécifique à la station. Lequel de ces deux systèmes devrait primer, toutes choses égales ? L'ordre des mots que j'ai utilisé indique ma préférence.

Le mot «écosystème» est une autre source possible d'erreurs. La confusion vient de ce que le mot recouvre deux idées. Certains considèrent que les écosystèmes forestiers se construisent par addition en partant d'en bas, et comprennent essentiellement la végétation et le sol. Ceux qui partent d'en haut conçoivent les écosystèmes forestiers comme un tout qui englobe le relief, le sol, le biote et l'atmosphère, soit tout ce qui forme l'ensemble espace-terre. Une étude de l'écosystème peut donc avoir deux sens : tenir compte d'autre chose que de la végétation (considérer le sol, la faune, l'eau, etc.), ou s'occuper du paysage tridimensionnel dans son ensemble et de tout ce qui s'y trouve.

L'aspect sans doute le plus nouveau aujourd'hui, et qui pose le plus grand défi à l'écologiste, c'est la re-conception du domaine forestier en tant que fournisseur de matières premières et de valeurs : eau, faune, flore, activités récréatives, esthétique, bois de construction et fibres. Il nous faut comprendre chaque pouce de terrain, chaque site forestier, dans son contexte régional si nous voulons l'utiliser de façon durable. Notre but est donc de comprendre les écosystèmes forestiers régionalement et localement, d'identifier leur «capital» qui doit être préservé si l'on veut pouvoir en «profiter» périodiquement sous forme d'eau, d'animaux, de plantes et de plaisirs esthétiques. Voilà le test qui attend l'évaluation des sites forestiers dans l'avenir. Voilà aussi le but que se sont donné les articles présentés ici.

Dans ce contexte, il est intéressant de se demander qui utilise et qui utilisera les résultats des évaluations des sites forestiers. Plusieurs articles remarquent qu'il faudrait s'enquérir des besoins des utilisateurs avant d'entreprendre le travail dans les bureaux ou sur le terrain. L'avantage de cette méthode, c'est que les résultats seront pertinents pour ceux qui auront été consultés. Par contre, l'inconvénient, c'est qu'on aura sans doute oublié un grand secteur de notre société. Si tant est que les écologistes sont libres, ils devraient peut-être se demander plus souvent quels sont les besoins de la société, tout en contrebalançant les exigences traditionnelles plus immédiates.

A review of forest site classification activities in Newfoundland and Labrador

by W.J. Meades[1] and B.A. Roberts[2]

Abstract

This paper provides a review of past and present forest site classification activities in Newfoundland and Labrador over the last thirty years. Initially, research concentrated on the development of a classification system using floristic and edaphic criteria to define forest types. This was followed by a period in which the relationships between forest types and stand productivity were assessed. Subsequently, pilot projects were undertaken in which the forest site classification was incorporated into the biophysical land classification approach and applied to forest capability mapping. In recent years the trend towards more intensive forest management has rekindled interest in forest site classification: emphasis is being placed on technology transfer of site classification to operational foresters in industry and government.

Key words: Forest classification, site classification, soils, vegetation, Newfoundland, Labrador, forest ecology

Résumé

Ce document présente un examen des activités antérieures et actuelles de classification des sites forestiers à Terre-Neuve et au Labrador, qui se sont déroulées au cours des trente dernières années. Au départ, la recherche portait sur l'élaboration d'un système de classification fondé sur des critères floristiques et édaphiques pour définir les types forestiers. Cette phase a été suivie par une période d'évaluation de la relation entre les types forestiers et la productivité du peuplement. Par la suite, des projets pilotes ont été entrepris; ils incorporaient la classification des sites forestiers à la classification biophysique du territoire et appliquaient ces données à la cartographie des ressources forestières. Depuis quelques années, la tendance à l'intensification de l'aménagement forestier a ravivé l'intérêt porté à la classification des sites forestiers; on a accentué le transfert, aux forestiers, des technologies de classification des sites, tant dans l'industrie qu'au gouvernement.

Mots clés : classification forestière, classification des sites, sols, végétation, Terre-Neuve, Labrador, écologie forestière.

Introduction

The land base of the island of Newfoundland consists of approximately 106,000 km^2 (Anonymous 1974). Productive forest cover makes up about 34% of this total; a further 22% is considered low-volume scrub forest. Barrens, peatlands, fresh water and cleared land account for some 19, 14, 10, and 1% respectively (Figure 1).

Seventeen tree and tall-shrub species exist but the three principle species are balsam fir, black spruce and white birch, which account for 95% of the volume with 50, 34 and 11%, respectively. Trembling aspen, eastern larch, white spruce and yellow birch are common, while white pine, common in the past and through the early years of this century, is in decline. The rarest coniferous and deciduous species are red pine and black ash, restricted to fewer than 25 very small stands or localities.

Labrador has a land base of 288,000 km^2. Most of the forest land is south of 56°N and falls within Forest Sections B13a and B31 (Rowe 1972), with smaller areas representing Forest Sections B12 and B1b. The area south of 56°N contains 5.5 million hectares of forest land supporting 334 million m^3 of wood. The most productive region of the Lower Churchill Basin and Goose Bay-Lake Melville area (Forest Management Unit 19) contains 0.36 million hectares with more than 40 million m^3 of timber, comprising 66% black spruce, 26% balsam fir and 8% a mixture of white spruce, larch, white birch and aspen (Anonymous 1975, 1982).

Robertson (1945) provided the first forest site classification for Newfoundland that recognized six forest types on the basis of dominance of undergrowth vegetation. The Newfoundland Royal Commission on Forestry (Kennedy 1955) provided a map prepared by G. Brown showing the general distribution of forest productivity zones. Since that time considerable research effort has been expended to provide a more comprehensive classification system that is sensitive to the needs of modern forest management. These needs include the ability to recognize ecological factors that limit forest productivity and control species composition both under natural succession and after disturbances such as cutting, fire and severe insect infestation. Intensive forest management also requires more detailed assessment of species-site relationships, equipment restrictions, and planting techniques with respect to specific vegetation and soil conditions.

During the past three decades three distinct but complementary research activities can be identified in this field: (1) site classification, (2) productivity correlation, (3) biophysical (ecological) land classification and mapping.

Damman (1963, 1964 and 1967) established the basic framework of forest types in Newfoundland on the basis of vegetation, soil and landform criteria. Wilton (1965) described five physiognomic forest types in Labrador covering three productivity classes. In Newfoundland correlations with forest productivity were provided in a series of mensurational studies (Bajzak *et al.* 1968, Page *et al.* 1970, Page and van Nostrand 1970). Damman's forest site classification was used in the calibration of the Canada Land Inventory Forest Capability Classification (Delaney 1974). Several pilot studies were conducted in Newfoundland and Labrador to assess the feasibility of the biophysical (ecological) land classification and mapping (Bajzak 1969, Bajzak 1973, Wells *et al.* 1972, Wells and Roberts 1973). Collectively, these studies have compiled a considerable quantity of baseline data. However much remains to be done with respect to specific applications to forest management.

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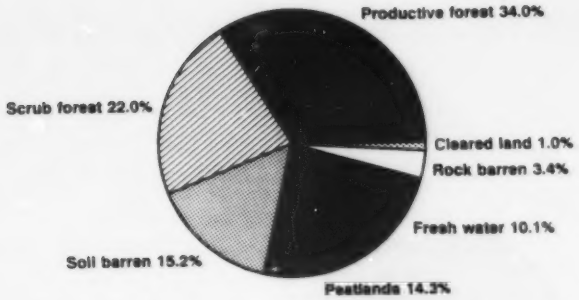


Figure 1. Percent of land area occupied by Forest Inventory cover types (after Anonymous 1974).

The purpose of this paper is to:

(1) provide a current review of forest site classification literature in Newfoundland and Labrador;

(2) give a brief overview of the concepts and methodology followed in developing site classification and related mapping activities; and

(3) discuss future requirements for site classification research and technology transfer with respect to forest management in the region.

Forest Site Classification

Regional forest site classifications exist for the northern (Damman 1963), central (Damman 1964), western (Damman 1967) and eastern (Meades 1986) portions of insular Newfoundland. The fundamental unit in these classifications is the 'forest type' which is defined by a combination of soil and vegetation criteria. All mature successional stages of forest development are included in the classification and the successional relationships between climax and subclimax types is inferred through a comparison of undisturbed and disturbed toposequences on similar parent materials within an area of homogenous regional climate (Figure 2).

In most cases, the Newfoundland forest type is defined through a combination of vegetation classification using the relevé methodology (Mueller-Dombois and Ellenberg 1974) and soil characteristics of the site. Thus the vegetation type, although it is an important component of the forest type classification, is not synonymous with the concept of forest type. Characteristic species and differential species are used where possible to define associations, sub-associations and variants. Where this is not feasible, the physiognomy of the stand and dominance are also used.

Damman (1964) explained this approach as follows: "It will not add to the clarity of the distinction between the vegetation units, if, in order to stay in agreement with the original concepts of the Zürich-Montpellier School one recognizes those units on the basis of differential and characteristic species when the dominance of another species is the primary and most obvious characteristic."

During the period when Damman undertook most of his field studies (1957-67), soil classification systems did not adequately differentiate the variety of soils found in this region. Consequently, he used a combination of approaches adopted from Kubiena (1953) and the National Soil Survey Committee (1958, 1963) to identify soils at the subgroup level. In addition to soil taxonomy, the soil moisture regime (adapted from Hills 1954), texture and parent materials were used to characterize soil conditions at approximately the family level (Damman 1967).

It is important to note that the vegetation type is not consistently defined at the same level of abstraction in the vegetation classification hierarchy. Associations, sub-associations and variants are all flexibly used to define vegetation types. Similarly, soil taxonomy, texture or moisture regime may be given preferential weighting in separating types as necessity dictates. Also, in the black spruce-feathermoss forests of central Newfoundland, floristic separation of types was impossible because of the moderating influence of a deep raw humus layer (Damman 1964). Yet it was obvious that these forests represented a wide range of productivity and in some cases were of fire origin while in other cases were edaphically stable. Accordingly, the black spruce-moss forests were divided into five forest types on the basis of soil texture, presence or absence of seepage and depth to bedrock.

The forest types defined by Damman (1963, 1964, 1967) and Meades (1986) are similar in concept to the Hills' (1954) site type and the Lacate (1969) land type. There is also general agreement with the concepts of ecosystem type and ecosystem association used in the Biogeoclimatic Classification (BEC) in British Columbia (Krajina 1969, Pojar *et al.* 1987) and Alberta (Corns and Annas 1986). However, the more flexible assignment of the forest vegetation type irrespective of position in the phytosociological hierarchy is an important distinction. Also, although Damman (1983) described ecoregions for Newfoundland and studied plant distributions in relation to climate (Damman 1965, 1976), there is no climatic hierarchy comparable to the BEC system in Newfoundland. Newfoundland forest types would probably fall within the definition of an operational group (Jones *et al.* 1983); however, the methods used to define forest vegetation types in this region are quite different. Also, there is considerably greater emphasis on the topographic and successional relationships of the forest types.

In summary, the Newfoundland forest classification as developed by Damman (1963, 1964, 1967) and Meades (1986) has many conceptual parallels to systems developed in other regions of Canada. However, caution should be exercised in drawing direct comparisons because the system incorporates a wide variety of methodology applied in a unique manner to develop a practical classification for application to forestry needs.

Gillet (1954, 1960, 1963) lists more than 140 vascular plants from Goose Bay and northern Labrador and reviews the early botanical expeditions. Brassard and Williams (1975) report 79 species of liverworts, while Brassard and Weber (1978) list 348 species of mosses for Labrador. The vegetation history of southeastern Labrador on the basis of its pollen stratigraphy is reported by Lamb (1984) and Engstrom and Hansen (1985).

Wilton (1965) used Hustich's (1949) classification of forest types in Labrador to subdivide the vast extent of forests into productivity classes. The approach is that of the Finnish Cajander School which uses the understory vegetation to identify a soil moisture series. Linteau (1955) developed a similar classification in southern Labrador. These classifications are summarized in Table 1. The approach and methodology differs considerably from the one used in insular Newfoundland, with little emphasis on topographic and successional relationships of the forest types.

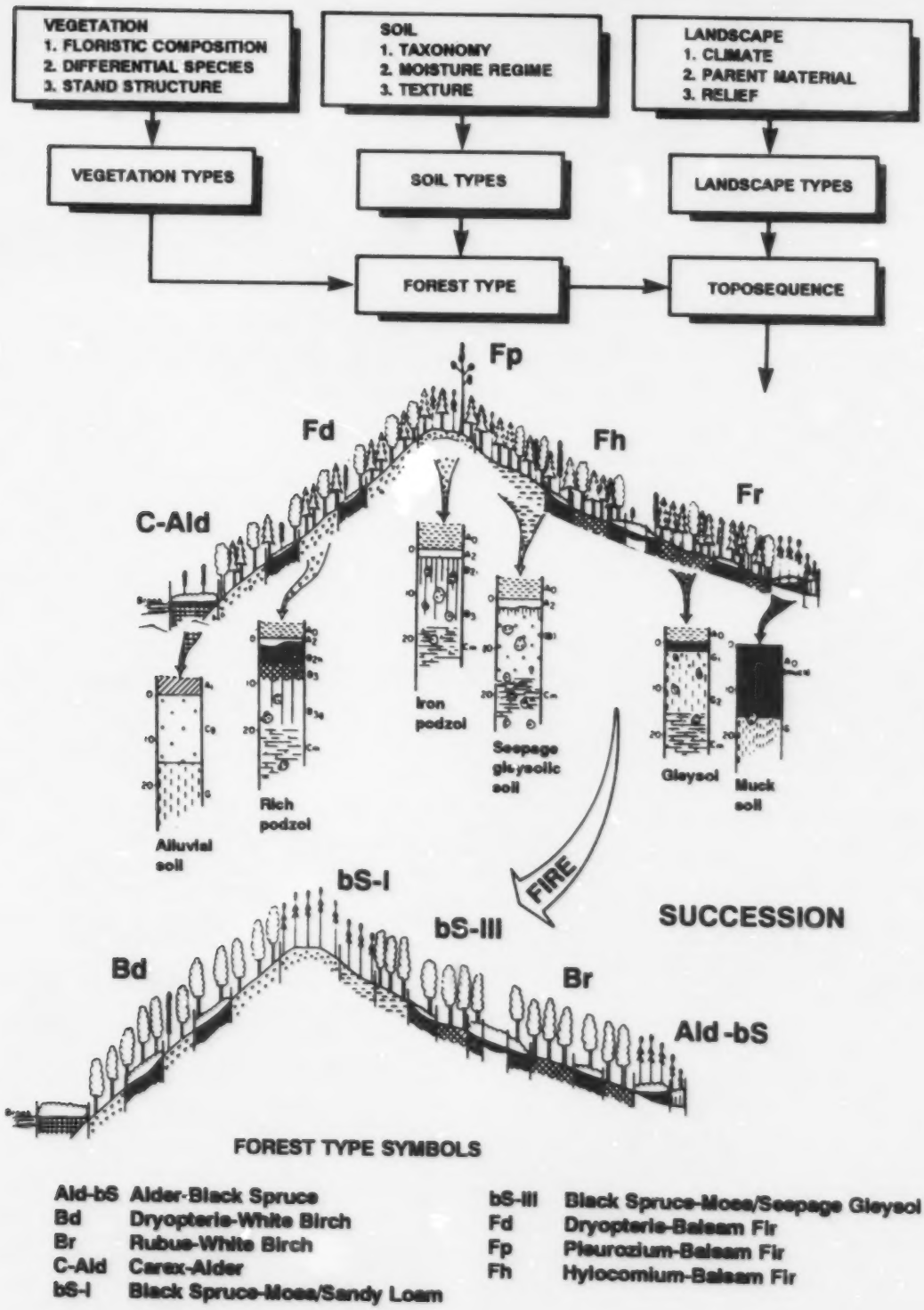


Figure 2. Summary of the approaches used in the development of the Newfoundland forest site classification, after Damman (1963, 1964, 1967) and Meades (1986).

Table 1. A summary of forest type classifications for Labrador (after Wilton 1965).

Northeastern Coniferous Section (Linteau 1955)	Site Class	Labrador Peninsula (Hustich 1949)	Newfoundland Labrador (Wilton 1965)
I. Herb and Fern Forests 1. *Dryopteris-Oxalis* 2. *Cornus-Maianthemum* 3. *Pteridium-Aralia*	I		
II. Herb and Moss Forests A. *Hylocomium* moss 1. *Hylocomium-Oxalis* 2. *Hylocomium-Cornus* B. *Calliergon* and Hypnum Moss 1. *Calliergon-Oxalis* 2. *Hypnum-Cornus*	II	A. Moist Series 1. Rich conifer forest 2. Conifer bunchberry forest	A. Moist Series Fir-spruce-birch/rich herb
III. Moss Forests 1. *Hypnum-Hylocomium* 2. *Hypnum*	II	3. Conifer feathermoss forest	B. Dry series Spruce-fir-feathermoss
IV. Moss and Dwarf Shrub Forest 1. *Hypnum-Kalmia* 2. *Calliergon-Ledum* 3. *Calliergon-Vaccinium* 4. *Kalmia-Ledum*	III	B. West Series 1. Black spruce muskeg 2. Rich swamp forest	C. Wet Series Spruce-fir/dwarf shrub
V. Peat Moss and Dwarf Shrub Forest 1. *Sphagnum-Rubus* 2. *Sphagnum-Ledum*	IV	3. Open bog forest	D. Very wet series Spruce/sphagnum
VI. Lichen and Dwarf Shrub Forest 1. *Kalmia-Vaccinium* 2. *Cladonia-Ledum* 3. *Cladonia-Vaccinium*	III	C. Dry series 1. Conifer dwarf shrub lichen forest 2. Conifer lichen forest 3. Conifer blueberry forest	E. Very dry series Spruce/lichen

Working in the Lake Melville region of central Labrador, Bajzak and Roberts (1984) recognized the following forest types:

I. Balsam fir-white birch forest

1. Balsam fir-herb-rich forests
2. Balsam fir-moss forests:
   Hylocomium subtype
   Pleurozium subtype
3. Alder-balsam fir forests
4. *Myrica-Sphagnum*-balsam fir forests
5. White birch forests

II. Black spruce forests

1. Black spruce-moss forests
2. *Cladonia*-black spruce forests
3. *Sphagnum*-black spruce forests

While cutting and fire are both common for insular Newfoundland, Labrador forests have not undergone extensive cutting except for a brief period in the 1970s and in the last few years. Wildfire has been the most important factor in forest succession.

Recently Foster (1983a, 1983b, 1984 and 1985) evaluated the fire history and the phytosociology of the forest vegetation of southeastern Labrador. This work examined the vegetation pattern and diversity of its fire-origin extensive black spruce stands. The history and characteristics of the fire-origin white birch forests (Foster and King 1986) also showed that regeneration from softwood to relatively pure white birch occurs frequently on moist and well-drained open sites if there is a nearby seed source, very much as it occurs in insular Newfoundland.

Correlations with Productivity

A series of mensurational studies on most productive forest types described by Damman was conducted by Canadian Forestry Service researchers between 1962 and 1970, as follows:

1. Central Newfoundland (Bajzak 1962, van Nostrand 1964);
2. Western Newfoundland (Bajzak *et al.* 1968);
3. Northern Newfoundland (Page *et al.* 1970);
4. Eastern Newfoundland (Page and van Nostrand 1970); and
5. Labrador (Wilton 1965).

The results of these studies were quite variable in that good correlation between yield and forest type could be established for some, but not all forest types. Thus Page (1970) concluded "the classification system cannot, alone, achieve desirable levels of accuracy for site index and basal area." He was basing his conclusion on eastern Newfoundland where wind is an overriding ecological factor controlling tree height growth. Roberts and Bajzak (1984) clearly demonstrated a distinct separation of forest site index curves related to forest types described by Damman (1964) in central Newfoundland (Figure 3).

Recognizing soil seepage and its contribution to forest growth is an important factor in understanding the soils of

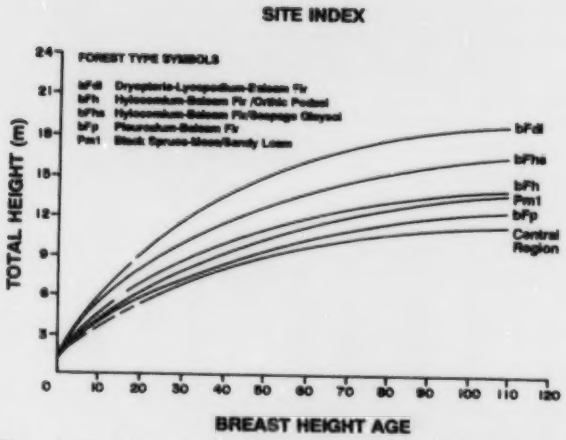
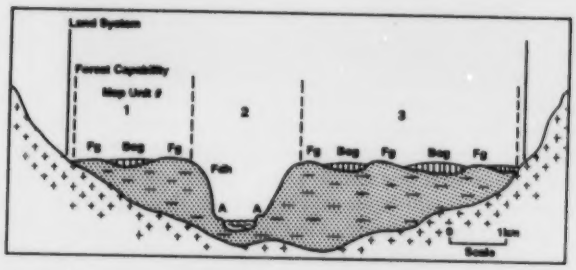


Figure 3. Site index curve for forest types (Damman 1964) in central Newfoundland (after Roberts and Bajzak 1984).



MAP UNIT # 1:50,000 Scale	FOREST TYPES (Damman 1967)	CAPABILITY CLASS & SUBCLASS	CAPABILITY MAP SYMBOL
1	Gaultheria-Balsam Fir (Fg)	5^{r}_{bF}	$\overset{a}{5^{r}_{bF}}\ \overset{a}{7^{t}_{w}}$
	Bog	7^{r}_{w}	
2	Dryopteris-Hylocomium-Balsam Fir (Fdh)	3^{p}_{bF}	$\overset{a}{3^{p}_{bF}}\ \overset{a}{7^{t}_{w}}$
	Alder Swamp (A)	7^{t}_{w}	
3	Gaultheria-Balsam Fir (Fg)	5^{r}_{bF}	$\overset{a}{5^{r}_{bF}}\ \overset{a}{7^{t}_{w}}$
	Bog	7^{t}_{w}	

Figure 4. An example of how the Damman forest types were integrated with the Canada Land Inventory-Forest Capability Mapping Project (after Delaney 1974). Symbols used: bF — Balsam Fir, W — moisture excess, M — moisture deficiency, F — low fertility.

central Newfoundland (Damman 1960, Roberts 1986). Soil seepage over fragipans, compact till or bedrock occurs in about half the 38 site types for seven different tree species in this part of the Boreal Forest. Many of the productive forest types are underlain by the most common soil subgroups, the Orthic and Gleyed Humo Ferric Podzols, which are well to imperfectly drained. The addition of soil seepage on long slopes usually makes little difference in terms of assessing soil drainage values. However, the mottling effect in lower B horizons and the differentiation of the wetter Orthic Gleysols with and without seepage can make a difference of 2-5 metres in site index and 20-40% in volume. The main factors of landform, slope length, soil texture and depth, as well as the quantity of precipitation greatly influence the quality and quantity of seepage and the amount of soil profile development. The additional moisture and nutrient supply in the driest months of mid-summer probably contribute to the much better growth in seepage areas. However, to date, no attempt has been made to apply ecological forest types to inventory in Newfoundland. The Newfoundland Forestry Department uses regional growth and yield curves applied to cover-type working groups as the basis for forest inventory.

In 1966, the Newfoundland government became involved in the Canada Land Inventory to assess and map land for its potential use in forestry as well as for the development of its other resources. The approach and methodology used in this project is well documented (Beanlands and Damman 1967, Delaney 1974). Basically, the forest types described by Damman (1963, 1964, 1967) were used in combination with the mensurational data available for each major region to assign forest types to each productivity class. Since each of the Damman forest types is associated with characteristic soils, parent materials, moisture regime and topographic position, the unit can be mapped at a scale of 1:50 000 as a complex of forest types and capability classes (Figure 4). In most cases the forest types are assigned to one capability class or at most a range of two classes. There is also good agreement with subclasses which identify factors limiting tree growth on a particular forest type.

Ecological (Biophysical) Land Classification

Newfoundland and Labrador have been the locations of several pilot projects to assess the feasibility of ecological (biophysical) land classification and mapping using the approach described by Lacate (1969).

Wells *et al.* (1972) published a land system map (1:125 000 scale) and accompanying report for a 2771-km^2 area near Corner Brook in western Newfoundland. The work was completed by a team consisting of a geomorphologist, phytosociologist, pedologist, wildlife biologist and a recreation specialist. Land types were defined by a combination of soil series and forest types (after Damman 1967). The land types were illustrated through the use of cross-section diagrams of land systems cross-referenced to the land system map. Land-use interpretations at the land type level were made for forest, agriculture, wildlife and recreation capability. In addition, erosion hazard, equipment restrictions and vegetation competition were interpreted for application to forest management.

Bajzak (1973) provided a biophysical land classification of the Lake Melville area (1300 km^2) of central Labrador and accompanying map of land districts and land systems at a scale of 1:125 000. The approach was very similar to Wells *et al.* (1972) with the distribution of land types being illustrated by means of cross-section diagrams of land systems. Land capability for forestry, wildlife and recreation were provided at both the land system and land type level.

Wells and Roberts (1973) undertook biophysical land classification and mapping in a 70-km^2 area of central Newfoundland. Unlike the previous surveys, mapping in this project was at the land type level using a map scale of 1:15 840. Emphasis was placed on the application of biophysical mapping to forest management needs. Interpretations were provided on forest capability, erosion hazard, equipment restrictions,

vegetation competition, species suitability, logging operations, natural regeneration, trafficability, ease of road construction and forest nursery suitability.

Ecoregion maps of Labrador (Lopoukhine *et al.* 1978) and insular Newfoundland (Damman 1983) have been completed. Meades (unpublished) consolidated the 27 physiographic ecoregions of Lopoukhine *et al.* (1978) into 10 climatic ecoregions for the National Ecoclimatic Regions of Canada map (Ecoregions Working Group 1989). The ecoregion maps are used in forestry to identify regional variation in forest composition and successional trends that are climate-related. Also, the Protected Areas Association of Newfoundland and Labrador is using these ecoregions to delineate natural regions for the purposes of protecting representative habitats in Ecological Reserves and Wilderness Areas.

Roberts and Bajzak (1984) revised the soils and drainage categories for the productive Damman forest types and provided correlations of forest types to forest capability, soil parent materials and landforms, soil drainage and soil subgroups for 38 site types and seven different tree species in central Newfoundland.

In addition to classifying forest types, the problems of mapping site types through the use of aerial photography have been recognized (Bajzak 1964). Damman (1979) states that the lowest scale at which sub-associations or associations can be mapped is 1:20,000; at lower scales the map units will include community complexes. Frequently, the extent of a forest site type is inferred by assessing the slope, parent material and drainage conditions in combination with the composition and growth of the forest.

The increased emphasis on intensive forest management and environmental issues in this province over the last decade has set the stage for application of site classification and mapping technology to land-use management.

Technology Transfer

In 1985, Forestry Canada initiated a series of field workshops to demonstrate to government and industry foresters in the province some of the benefits of applying ecological site classification to forest site assessment and prescription. This was closely followed by an independent review of forest site classification in Newfoundland by the Newfoundland Department of Forest Resources and Lands to develop recommendations for future applications of site classification to forest management in the province. The review concluded that the "Damman" site classification system, because it was ecological in scope, provided the best basis for future work in the province. The review also recommended a pilot study to consolidate existing data sources and develop a mapping system that could integrate site attributes and inventory in a Geographic Information System (GIS) (Bouzane 1987). These events precipitated renewed interest in the topic and led to greater federal-provincial co-operation on a site classification.

Van Kesteren (1986) developed a method for mapping the environmental sensitivity of land to forest harvesting in central and western Newfoundland. The approach utilizes aerial photo interpretation at the ecosite levels of the ecological land classification. Ecosites are assessed in terms of their erodibility (on the basis of gross texture of surficial material), slope and soil ground water condition. This assessment places the ecosite in one of six land sensitivity classes (L0-L5) representing zero to extreme sensitivity. Preliminary guidelines for harvesting are provided.

During the same period Forestry Canada and the Newfoundland Department of Forestry and Agriculture co-operated on the development of a site classification manual for all regions of the Island under the Forestry Resource Development Agreement (Meades and Moores 1989). The field manual is similar to those developed elsewhere in Canada, with somewhat more emphasis on successional trends and harvesting sensitivity in the management interpretations (Figure 5). A more in-depth description of the manual and its application to forest management is provided in Meades (1991).

Current Activities

Since the release of the *Forest Site Classification Manual* (Meades and Moores 1990) several field workshops have been held throughout Newfoundland to acquaint operational foresters with the application of ecological site classification to forest management. The classification system has been generally well received but it will probably take a few years before it is fully implemented in forest operations.

The environmental sensitivity mapping developed by van Kesteren (1986) has been improved and applied to industrial harvesting in the Corner Brook municipal watershed (van Kesteren 1992). The provincial Department of Forestry and Agriculture plans to initiate contracts to apply this sensitivity rating to a number of watersheds that are scheduled for harvesting.

Field work has been completed on the classification of seral vegetation on cutovers across a variety of forest types in central and western Newfoundland. This study, when completed, will make possible the pre-harvest prediction of vegetation succession on a variety of sites during the period between harvest and crown closure. The information can be used for flagging potential vegetation management problems and planning wildlife habitat availability.

Autecological studies by Forestry Canada are concentrating on analysis of growth, seed production, regeneration and competition relationships between important trees and shrubs (red pine, tamarack, white spruce and *Kalmia angustifolia*) throughout a wide range of site conditions (Roberts and van Nostrand 1984, Roberts 1985a, Roberts 1985b, Mallik 1987, Roberts 1989). The effects of seepage waters on soil productivity for forest growth and terrain sensitivity to harvesting and road construction are also being investigated (Roberts 1986).

These studies are conducted within the site classification framework and complement the site classification by providing site-specific site index curves, regeneration prescriptions and environmental guidelines for harvesting and road construction.

Future Directions in Site Classification

It is clear that development of the *Forest Site Classification Manual* (Meades and Moores 1989) is not an end but a beginning, and there will be a continuing requirement for training, technology transfer and research. Training will be greatly enhanced by the adoption of site classification in the university and technology forestry programs of the province.

Currently there is no site manual for Labrador and differences in climate and soil conditions preclude extrapolation

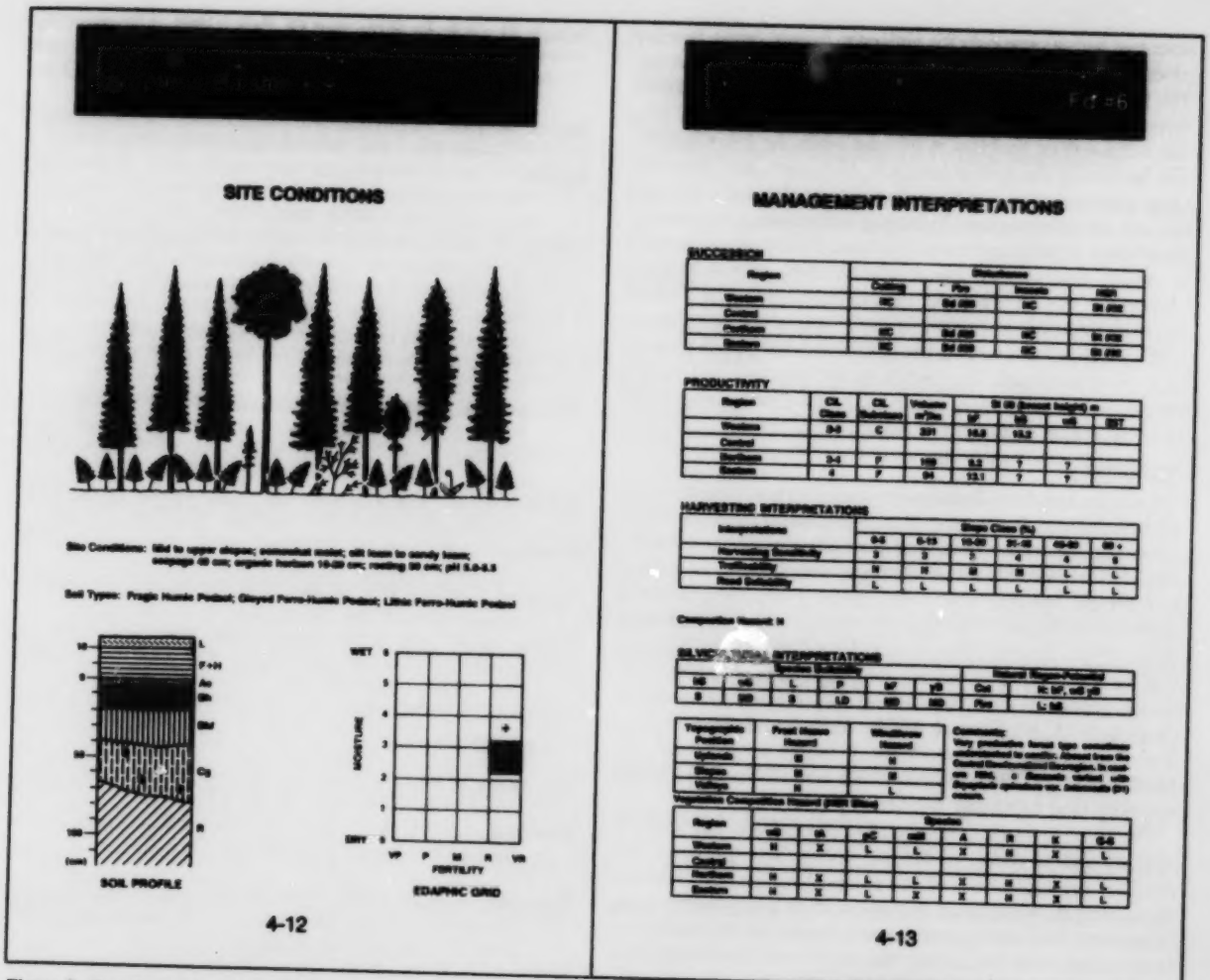


Figure 5. Fact sheet and management interpretation for the Dryopteris-Balsam Fir forest type (Meades and Moore 1989). Symbols used are as follows: *Succession*; NC — no change, Bd — Dryopteris-Birch type; Bt — Birch Thickets, # refers to the corresponding fact sheet number. *Productivity*; CLI — Canada Land Inventory for Forestry, C — climate, F — fertility, bF — Balsam Fir, bS — Black spruce, wS — White Spruce, SI — site index, EST — estimate. *Harvesting Interpretations*; L — low, M — medium, H — high, sensitivity 1 — low, 5 — high. *Silvicultural Interpretation*; S — satisfactory, MD — most desirable, L — least desirable, Species bS — Black Spruce, wS — White Spruce, L — Larch, P — Pine, bF — Balsam Fir, yB — Yellow Birch *Frost and Windthrow Hazard*; H — high, M — medium, L — low. *Vegetation Competition Hazard*; Species wB — White Birch, tA — trembling aspen, pC — pin cherry, mM — mountain maple, A — Alder, R — Raspberry, K — Kalmia, G-S — grasses and sedges. *Edaphic Grid*; fertility, VP — very poor, P — poor, M - medium, R — rich, VR — very rich.

of results from the Island. Given the prevalence of sensitive sites in the area, development of a forest ecological site classification for Management Unit 19 (Anonymous 1982) should have a high priority.

From a research perspective, fine-tuning of the site classification is needed in several areas. Seral vegetation succession on cutovers is handled only in a preliminary manner in the manual. Forestry Canada has completed field surveys of harvested areas and when the data are analyzed they will show changes in vegetation composition that occur up to crown closure over a wide range of site types. This data set needs to be extended into managed sites, including natural and prescribed burns, so that guidelines for vegetation management can be expanded for assessing changes in wildlife habitat associated with forestry activities.

The site indices used in productivity estimates are from a very limited data base in old growth. Incorporating the site classification into permanent inventory plots by the Department of Agriculture and Forestry will greatly improve the reliability of these predictions in the future. The species and site suitability interpretations also need to be empirically validated with permanent plots in operational plantations. Only then can we say with some certainty to what extent one species can outperform another species on a specific site type.

The adoption of sustainable development as an ethic for forest management in the new *Forestry Act of Newfoundland and Labrador* will bring with it an increased commitment to integrated resource management. The development of habitat supply models for wildlife on the basis of forest ecological classifications and succession models is considered an essential step in the implementation of integrated resource management.

Finally, the application of remote sensing technology to site classification should be vigorously explored. Conventional

inventory and site mapping is a high-cost, manual, and subjective process that is too quickly outdated by fire, insects and cutting. The high cost of human and monetary resources often forces foresters to use a single map base for many interpretations. This was not a serious problem in the past when the sole objective was harvesting the timber resource. However, now there are many themes that have to be explored at variable scales through the use of current data, including silviculture, succession, harvesting, wildlife and other concerns. Recent developments in remote sensing and computer technology appear to have opened the way for the rapid customized mapping of various themes at scales appropriate to specific objectives. Subsequent overlay analysis through the use of GIS technology can be used to develop landscape interpretations for planning and policy development at all levels of concern (i.e., the forest management unit, the region or the province).

Summary

Over the last three decades site classification systems have been developed for insular Newfoundland (Damman 1963, 1964, 1967; Meades 1986) and for Labrador (Wilton 1965). Attempts to correlate forest site types with stand growth have had mixed results, with some authors reporting success (Roberts and Bajzak 1984) and others a lack of good correlation (Page 1970). Several pilot projects have clearly demonstrated that the forest types as defined by Damman (1964, 1967) are readily applicable to ecological land classification and mapping (Bajzak 1973, Wells *et al.* 1972, Wells and Roberts 1973). The Canada Land Inventory for Forestry project used the Damman forest site classification as a basis for stratifying and mapping land capability for forestry (Delaney 1974).

The trend towards more intensive silviculture, particularly spacing and planting, in the last decade has increased the need for the application of forest site classification to forest management. Vegetation management is a key component of current silviculture practice and its success depends to a large extent on understanding the composition and succession of seral vegetation types after harvest. For this reason, research at the Newfoundland Forestry Centre in recent years has dedicated considerable effort to autecological studies of key species and classification of seral vegetation types. In the future, technological advances in the development of computer-automated geographic information systems (complemented with improved remote sensing capability) will provide the forest community with a timely opportunity to apply forest site classification information to forest management at the landscape level.

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Forest site classification in New Brunswick

by Colin Bowling[1] and Vincent Zelazny[2]

Abstract

Six site classification field guides covering nine site regions were published in March, 1989. They completed the design phase of a province-wide site classification program begun in 1981. The site classification system is designed as an on-site, preharvest assessment tool for use in mature and overmature natural stands. It incorporates easily recognizable vegetation and soil characteristics to classify each stand into a Vegetation Type (VT), a Soil Type (ST), and a Treatment Unit (TU). Forest management and silvicultural interpretations are given for each TU, with the primary interpretation being site productivity.

Résumé

En mars 1989, six guides pratiques de classification des sites portant sur neuf régions ont été publiés. Ils complètent ainsi la phase du programme provincial de classification des sites, entrepris en 1981. Le système de classification est conçu comme un outil d'évaluation prérécolte destiné à être utilisé sur le terrain, dans les peuplements naturels âgés et surâgés. Il fait appel à des caractéristiques du sol et de la végétation faciles à identifier afin de classer chaque peuplement dans un type de végétation (VT), un type de sol (ST) et une unité de traitement (TU). Des considérations relatives à l'aménagement et à la sylviculture sont présentées pour chaque TU, notamment sur le potentiel du site.

Introduction

Forest site classification efforts in New Brunswick have progressed sporadically since 1937 when the province was part of Haliday's "Forest Classification for Canada." A very thorough review of subsequent attempts at site classification in Atlantic Canada is provided by Page *et al.* (1979). For New Brunswick in particular, three of these attempts were province-wide classification systems, namely Loucks (1962), the Canada Land Inventory program of the late 1960s (McCormack 1970) and the unpublished work of Crampton (1973).

Although the first two pieces of work have been useful for broad planning purposes, they are of very limited operational value to forest managers either because of their scale or because of a lack of sufficiently precise growth and yield data. Crampton could not find meaningful relationships between productivity and his classification units, which were based on Loucks' ecoregions, bedrock and surficial geology, soil drainage and relief. His work was not carried forward.

During the late 1970s, projections of a province-wide, 20-year shortfall in softwood supply led to a series of policy decisions that drastically altered the way forest management was to be carried out in New Brunswick. In a very short time, the province's forest inventory system was redesigned and the forest resource photographed (true-colour) and interpreted at a scale of 1:12 500. All data were captured on a geographic information system (GIS) made up of a PRIME mini-computer and ARC/INFO software supplied by Environmental Systems Research Institute Corporation of California.

Wood supply analyses were to be done every five years, and along with operational silviculture decisions, were now the responsibility of the major forest companies. It became readily apparent that one of the biggest gaps in the information base on which much of the wood supply analyses depended, were reliable growth and yield data on a site-specific basis, and the ability to represent spatially the distribution of sites across the landscape.

In the spring of 1981, within the framework of this new forest management environment, an inter-agency group now called the New Brunswick Forest Site Classification Technical Committee proposed the design of a province-wide site classification system. The objective was to develop a system using the measurable features of the physical environment known to be principal determinants of stand productivity and silviculture treatment.

The provincial Department of Natural Resources and Energy was identified as the lead agency. A core of four to six people were hired on contract and funded through Federal-Provincial forestry subsidiary agreements. Much discussion ensued as to whether efforts should be map- or field guide-based, both approaches having their advantages and disadvantages. The field guide approach was chosen because of the short-term information needs, its lower cost, and because it was more site-specific and 'on the ground' than the mapping approach.

In addition to having productivity as its primary interpretation, the site classification system was designed as a pre-harvest, on-site assessment tool for use in mature and over-mature stands. It was aimed at the field-trained forest technician, and used easily assessed soil and vegetation features that fit in well with operational activities.

Approach

The non-hierarchical site classification system of van Groenewoud and Ruitenberg (1982) provided an initial framework for field sampling. Four levels of classification, from general to specific, describe climate, geomorphology, regolith, and site (Table 1). Each level is defined quantitatively, through the use of environmental features known to affect tree growth and productivity. This is different from many existing forest site classification systems which define each level through indirect, synoptic measures.

For example, Loucks (1962) used major changes in climax forest cover on 'zonal,' or average, sites to delineate and map areas of similar macroclimate (ecoregions). Preliminary ecoregion boundaries were then finalized after consulting available weather data. In contrast, climatic regions as defined by van Groenewoud (1984), were derived from

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Table 1. The four-level site classification system of van Groenewoud and Ruitenberg (1982), used as the basis for the New Brunswick site classification system

Unit	Description	Remarks
1. Climatic region	A region with a distinctive climate delineated by multivariate statistical analysis of meteorological data	These parameters constitute a broad control on forest growth and form the framework for meso- and microclimatic description.
2. Geomorphologic district	The surface expression of a major bedrock formation or group, modified by glaciation and fluvial erosion.	These parameters provide the first-order controls on drainage, topography, mesoclimate and nutrient supply.
3. Regolith system	a) Form and texture of land-forms such as lodgement till, ablation till, outwash, alluvial deposits, etc.	These parameters greatly affect drainage and limit nutrition availability within the regolith.
	b) Lithologic-mineralogic composition (including percentage of material derived from different rock units and their secondary products) and structure (cleavage and fracturing) of the regolith material.	
4. Site type	a) Soil profile characteristics b) Microdrainage c) Slope d) Position on slope e) Aspect f) Microclimate, etc.	All of these parameters influence soil chemistry, soil physical properties or local climate, singly or together, and hence influence forest growth at the individual tree and stand level.

multivariate analyses of 30 years of meteorological data collected across a province-wide network of weather stations.

Each approach has its strengths and shortcomings. Loucks' indirect approach was subject to forest cover differences responding not to climate alone, but also to changes in other ecological factors, such as fertility due to differences in geological materials, for example. Van Groenewoud's direct method was constrained by the availability of data (relative humidity data were not available, for example) and by the lack of weather stations in a large area of the province.

The concept of the edatopic grid was also used to help in stratification for sample plot selection. An edatopic grid is an arrangement of stand types (ordination) in two dimensions whose axes represent soil moisture regime (SMR) and soil nutrient regime (SNR) (Klinka and Carter 1990) (Figure 1). Stand types are arranged on the grid so that similar stands (with respect to SMR and SNR) are close together, dissimilar ones far apart. The assumption here is that SMR and SNR are major factors driving stand species composition and development within a climate region. Sampling was carried out in all portions of the edatopic grid in order to cover the complete range in both nutrient and moisture regime within a climate region.

Within this framework, tree growth, soils, and vegetation data were collected between 1982 and 1988 in approximately 2100 mature and overmature natural stands. All forest cover types were sampled, although proportionately more plots were established in softwood and softwood-hardwood forests than in hardwood forests because growth and yield data needs were much greater for softwoods.

As an understanding of the relationships among soil, vegetation, and productivity developed, the concepts of Site Region and Treatment Unit evolved. These are site units that draw together the essential information from the four levels of classification (as described in Table 1) to distinguish sites on the basis of productivity. They are intended to be practical and easy to identify from an operational standpoint.

A Site Region is a landscape unit recognized on the basis of regional climate as derived from meteorological data (van Groenewoud 1984) (Level 1 above), bedrock and physiography (van Groenewoud and Ruitenberg 1982) (Level 2 above), and the species composition of vegetation on zonal sites (Loucks 1962). Site Region boundaries result from the melding of all three information sources, in a attempt to maximize the strengths and minimize the weaknesses of each. There are nine Site Regions in the province (Figure 2).

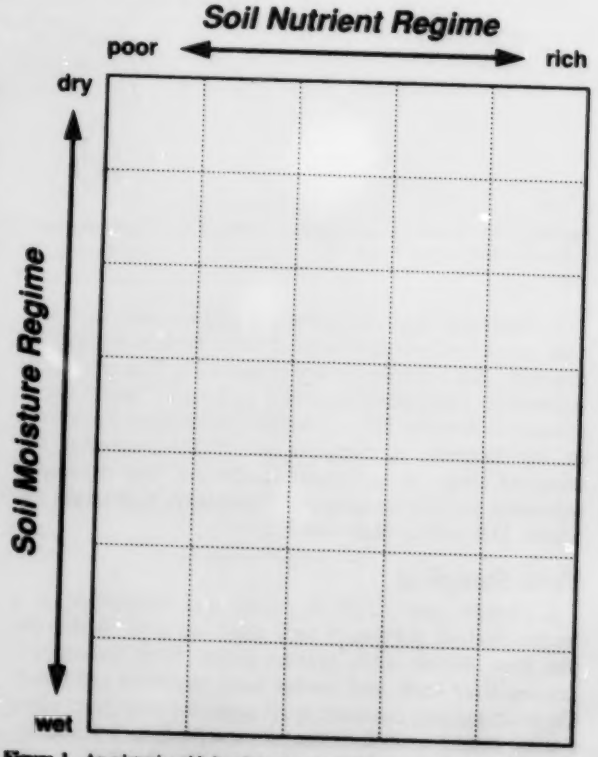

Figure 1. An edatopic grid showing relative nutrient and moisture regime cells.

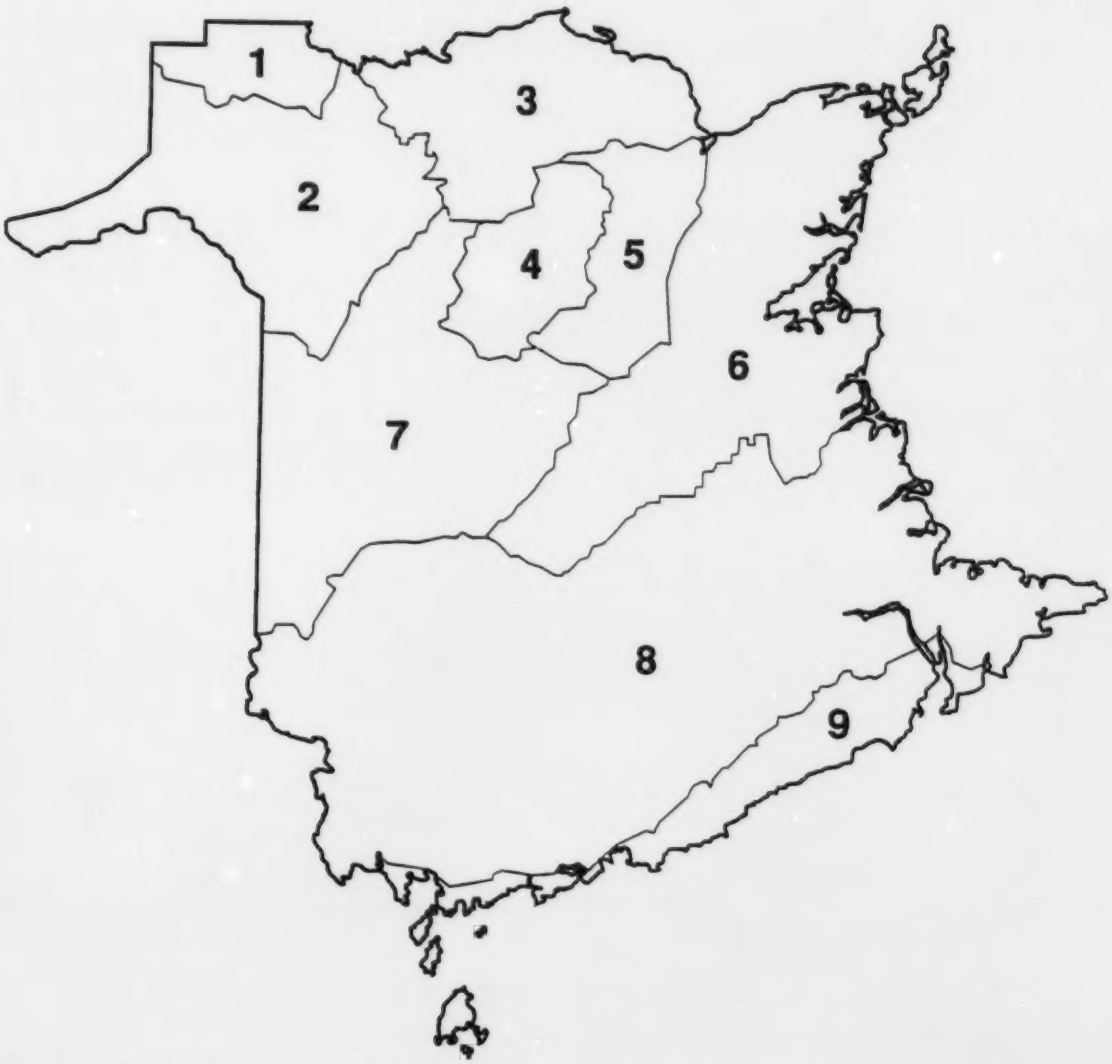

Figure 2. New Brunswick Site Regions. 1. Kedgwick, 2. Restigouche, 3. Upsalquitch, 4. Big Bald, 5. Sevogle, 6. Cains-Tracadie, 7. Napadogan-Tobique, 8. Harvey-Harcourt, 9. Fundy.

A Treatment Unit (TU) is a site-specific landscape unit with a relatively narrow range in both nutrient regime and drainage, and a certain level of productivity for commercial softwoods. Information collected at Levels 3 and 4 above are used to describe TUs, all within a hierarchical framework of Site Regions. A complete set of TUs, covering the observed range of ecological conditions, was developed separately for each Site Region. There are between eight and fifteen TUs within each Site Region.

Field Sampling

A circular plot 12 m in radius was established at a 'representative' portion of each stand sampled. Within the plot, trees, shrubs, herbs, grasses, sedges, ferns, clubmosses, lichens, liverworts, and mosses were identified and listed. Cover/abundance estimates were made for each plant using a scale from 1 (<8% of the plot covered) to 5 (>64%), a modification of the octave scale of Gauch (1982).

A soil pit was dug within each plot and described as to horizonation, depth of rooting and mottling, coarse fragment content, texture, and other morphological characteristics. In addition, 20 pebbles were collected from the lowermost (usually C) horizon for later lithological identification.

Where available, three or four dominant or co-dominant healthy, unsuppressed trees of the major coniferous species (white spruce (*Picea glauca*), red spruce (*Picea rubens*), black spruce (*Picea mariana*), balsam fir (*Abies balsamea*), and jack pine (*Pinus banksiana*)) were measured for total height, breast height age, and diameter at breast height. At the end of each plot establishment season (usually mid-September), all plot data were collated to choose approximately 30% of the plots for revisits and detailed stem analysis during the following three months. By the end of 1988, approximately 2600 trees on 580 plots had been felled, sectioned and measured.

Data Analysis

Vegetation

One of the fundamental concepts behind the site classification system was that the vegetation and soil components of the landscape could be independently analyzed, sorted, and subsequently brought together and classified into meaningful units for operational forest management.

Vegetation data were analyzed for each Site Region separately, with the objective of developing a Site Region-specific vegetation key. Taking a cue from site classification efforts in Ontario (Jones *et al.* 1982), this was accomplished by first using ordination and classification programs (DECORANA and TWINSPAN; Gauch 1982) to give an initial classification. A key-simulation program was then developed to refine the classification. Resulting Vegetation Types (VTs) represent the entire range of mature vegetation communities occurring naturally across the landscape within the limits of each Site Region's dataset (Figure 3).

A VT is a recurring, mature vegetation community determined by the presence or abundance of certain indicator plants. Each VT is described in terms of its common or distinctive overstory and understory vegetation components (Table 2). The species composition of any vegetation community reflects, among other things, soil conditions and processes related to plant nutrition and site productivity. This property of vegetation communities arises from the tendency of individual species to survive under certain soil conditions, and to fail under others. Species composition information conveyed by VTs also has important implications for natural stand development and competition.

Soils

As with vegetation, soils data were analyzed with the objective of deriving a Site Region-specific soil type (ST) key. In contrast to the VT key, divisions of a ST key were not designed to distinguish naturally occurring units per se, but to maximize the distinctiveness of STs in terms of tree productivity. As a result, STs are empirical, not taxonomic units. Specifically, each ST is a grouping of morphologically similar soils having a certain productivity as determined by site index (height (m) at 50 years breast height age) of dominant trees in natural stands. Soil types are identified through the use of variables such as drainage, depth to a compact layer, rooting space, mode of deposition, lithology, coarse fragment content, and horizon thickness.

Before detailed analysis began, decisions were made *a priori* to analyze organic soils (forest floor depth >40 cm) separately from mineral soils, to exclude old fields (Ap horizon present), and to analyze well and rapidly drained sites as a group, and moderately-well drained and wetter mineral soils as another group. Given these decisions, variables selected at lower levels of a ST key were present because they usually resulted in significant differences in site index for at least one of the major coniferous species listed earlier (Figure 4).

Productivity

Site quality effects on yield are most strongly expressed in the growth of managed stands, where the impact on yield of variation in stocking, defoliation by insects, disease, and

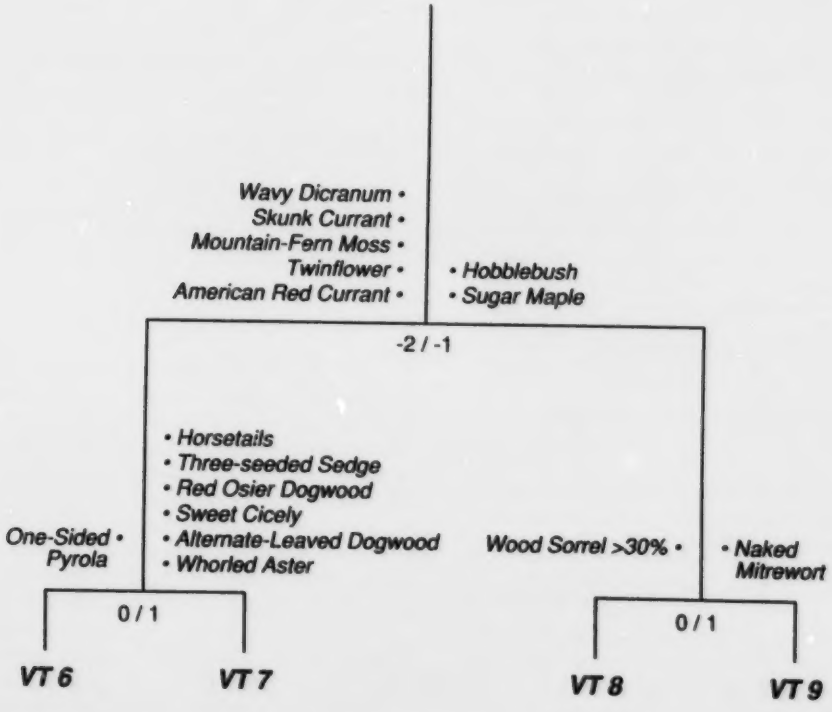

Figure 3. A portion of the Vegetation Type (VT) field key for the Restigouche site region. The dichotomous key employs common names for species because this presentation format was preferred by the client group. Full species nomenclature and directions for keying-out sites in the field are provided in the New Brunswick site classification field guides (from Zelazny *et al.* 1989).

Table 2. Soil Types (STs) and Vegetation Types (VTs) in the Restigouche site region. STs are defined in terms of local site or soil profile characteristics and VTs are characterized by dominant overstory species and dominant and/or distinctive understory species (after Zelazny *et al.* 1989).

Soil type	Soil type name	Characteristic soil features
ST 1	Wet	Average duff thickness = 16 cm
ST 2	Moist	Moderately well and imperfectly drained
ST 3	Calcareous	Derived from calcareous rocks or sediments
ST 4	Compact basal till	Mean maximum rooting depth = 38 cm
ST 5	Deep loamy	Mean maximum rooting depth = 50 cm
ST 6	Poor loamy	Derived from acidic igneous rocks
ST 7	Droughty	Rapidly drained, usually with a coarse-textured C horizon
Vegetation type	**Dominant overstory species[1]**	**Dominant and/or distinctive understory species**
VT 1	bS rS bF	*Pleurozium schreberi, Bazzania trilobata*
VT 2	bF rS	*Cornus canadensis, Oxalis montana*
VT 3	rS bF wB	*Bazzania trilobata, Lonicera canadensis*
VT 4	bF wB rM	*Clintonia borealis, Dicranum scoparium*
VT 5	bF yB wS	*Oxalis montana*
VT 6	bF wS	*Hylocomium splendens, Viola* spp.
VT 7	bF cE wS	*Rubus pubescens, Mitella nuda*
VT 8	bF yB wS	*Clintonia borealis, Galium triflorum*
VT 9	bF wS yB	*Corylus cornuta, Viola* spp.
VT 10	yB sM bF	*Dryopteris* spp., *Lycopodium lucidulum*
VT 11	Be sM	*Acer pensylvanicum*
VT 12	sM yB Be	*Acer spicatum, Streptopus roseus*

[1]bS = black spruce, rS = red spruce, wS = white spruce, bF = balsam fir, Ce = eastern white cedar, wB = white birch, yB = yellow birch, rM = red maple, sM = sugar maple, Be = beech.

competition by undesireable species has been eliminated or at least minimized. Unfortunately, very few older plantations existed by site type or species to provide a sufficiently large data base for destructive sampling. As a result, stem analysis of dominant trees from natural stands was seen as the only reliable means to obtain growth and yield information by site.

Many site quality studies have successfully used site indices obtained from measurements of total tree height and breast height or total age as a measure of site quality, particularly for fire-origin or intolerant species (Carmean 1975). However, both balsam fir and red spruce are shade-tolerant and may display height growth patterns caused by variable overstory competition levels rather than by a site's inherent capability for tree growth, and these patterns can be uncovered only with stem analysis.

In addition, stem analysis revealed sometimes dramatic height and diameter growth reductions coincident with moderate to high levels of budworm feeding. These reductions could be easily seen on balsam fir and white spruce discs, and required adjustments to the growth

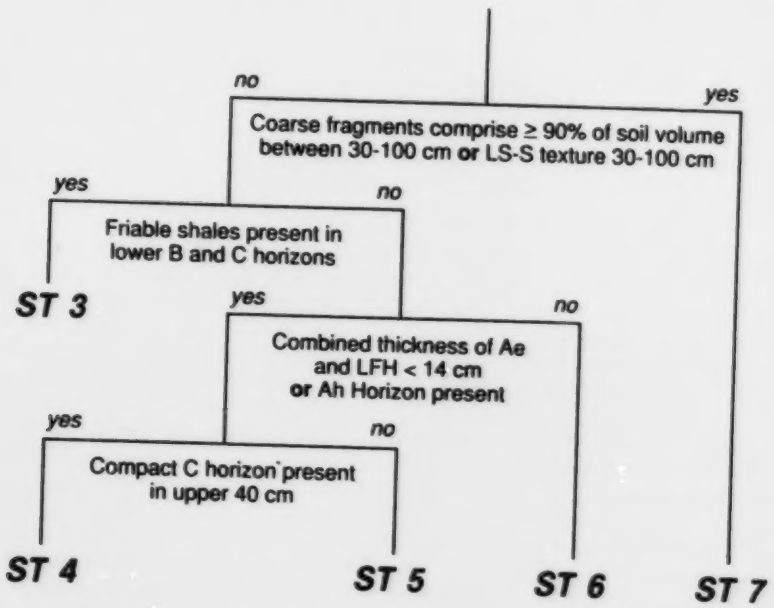

Figure 4. A portion of the Soil Type (ST) field key for the Restigouche site region. The dichotomous key employs a number of parameters that are determined from local site or soil profiles in the field. Aids for describing soils and directions for use of the key are provided in the New Brunswick site classification field guides (from Zelazny *et al.* 1989).

profiles. Procedures developed by Carmean (1972) were followed to adjust for the underestimation in each year's actual total height growth as a result of cutting discs below and not through a terminal whorl.

To estimate site-specific managed stand yields on a volume basis from tree data collected in natural stands, the best TU/species growth rates from these stem analysis data were submitted to an unpublished plantation growth model developed in-house by T. Erdle.

Treatment Unit Derivation

All possible combinations of STs and VTs and their TU designations are illustrated in a Site Region-specific TU grid. TU membership of each cell on the grid was assigned with two goals in mind: first, to maximize productivity differences between TUs, and second, to minimize soil and vegetation differences within TUs (Figure 5).

Each TU is identified by the number of the space that includes the square where the ST row and VT column intersect. Not all cells were represented by sample plots. Blank cells thought to be an ecologically valid combination but simply not sampled were interpolated into an adjacent TU. A dotted cell indicates not only no data for that particular ST-VT combination, but that the combination was deemed to not occur naturally.

Testing of the Keys

Approximately 15% of the total number of plots established within each Site Region were selected randomly from the dataset and not used in key development. Instead, these were used for in-house testing of the resulting keys and TU designations. In addition, other projects within both the provincial and federal forestry services had used the site classification datasheets and methodologies to collect plot-specific information. These data were graciously made available to be part of a test data set as well.

Testing was meant to check the precision of the keys and to uncover potential errors. At the VT and ST level, 'correct' classification meant that a plot had to be classified into a VT or ST that was a reasonable expression of that particular plant community or soil type. If, for example, a test plot was a wet black spruce-*Sphagnum* moss community and the VT or ST keys classified it into a moderately to well drained balsam fir-white spruce site, it would be recorded as a total misclassification.

At the TU level, if the misclassification of either the VT or the ST did not result in a change in TU, and if the site indices were within one standard deviation of the TU mean for most species, the classification was deemed successful. Averaged across all Site Regions, the VT and ST keys gave correct classifications approximately 75% of the time. When based on TUs, however, results improved to as high as 95% in some Site Regions. Complete misclassification occurred less than 10% of the time, a figure judged to be acceptable for this stage of evolution of the site classification system.

This type of testing is only one part of creating a usable site classification system. The other major criterion is whether it can be used effectively in the field. This was tested by having other projects use preliminary versions of the keys and data forms, and by operational trials in co-operation with forestry companies.

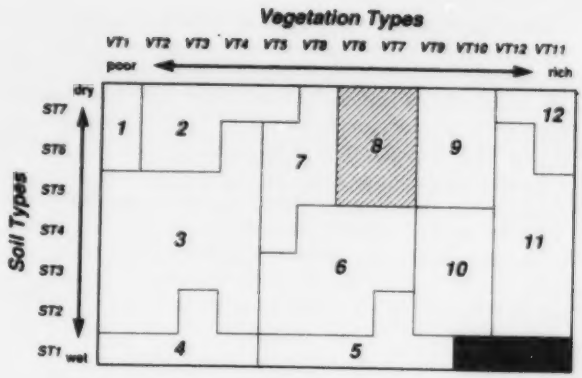

Figure 5. Treatment Unit (TU) grid for the Restigouche site region. *Poor* and *Rich* are relative nutrient rankings, and *Dry* and *Wet* are relative moisture regime rankings. Each of 12 TUs occupies a different portion of the nutrient/moisture regime grid. For example, TU 8 is highlighted in the diagram and includes sites that are keyed-out to Vegetation Type (VT) 6 or 7, and Soil Types (ST) 5, 6 or 7 (VT and ST names as in Table 2) (From Zelazny *et al.* 1989).

Current Situation

Field Guides

Six field guides covering nine Site Regions were published in March, 1989. This completed the original objective of designing a site classification system. In addition to the classification tools (the VT key, ST key, and TU grid) each field guide contains:

- Introductory information: includes step-by-step instructions for using the guide and a general ecological description of each Site Region.
- Verification information: includes material summarizing the average characteristics of VTs and STs to aid in verifying the results obtained with the keys.
- Interpretations: these appear on the TU interpretation sheets and contain information about managed stand yield, site index in natural stands, natural regeneration densities, and erosion, compaction, and windthrow hazards. Site index curves were developed from the stem analysis data (Ker and Bowling 1991) and are included in the field guides. Summaries of the derivation and definitions of these interpretations are also given.
- Soil description aids: include texture assessment key, horizon descriptors and drainage key.

A glossary of terms, a list of plants organized by life form and sorted by Latin name, a list of references, and a Site Region map in a back pouch completes each field guide.

Implementation

Since the publication of the field guides in 1989, all forest companies with responsibilities on Crown land have participated in implementing site classification. In New Brunswick today, the site classification system is being used to forecast yield from managed stands in wood supply analysis, and to priorize regenerating areas for silvicultural treatment on the basis of predicted managed stand yield.

Initially, the goal of the implementation program was to increase gradually the amount of on-the-ground preharvest site classification to 100% of harvest blocks by 1991. After the initial year, a number of companies expressed concern about the cost of obtaining these fairly large volumes of data in relation to the value of the information gained. After much discussion, the approach shifted to put greater emphasis on TU prediction based on existing sources of mapped resource information, rather than intensive field checks in all blocks.

Specifically, it was proposed that all existing site resource information be compiled into a uniform map coverage to be used for predicting TUs. With appropriate site quality maps, candidate blocks for precommercial thinning or planting could be prioritized on the basis of predicted site quality, and field-checked to verify the prediction. As a result, the number of areas to be ground-checked decreased by two-thirds from the original 100% proposal. Accurate site quality information confirmed by ground-truth could then be used to guide the process for final selection of silvicultural treatment areas.

Through the winter of 1989-90, existing land and forest resource information was compiled to produce ST and VT maps and by extension, TU maps. Soil types were mapped by interpreting and compiling existing sources of geology and soils information, as well as the approximately 3600 observations of soil and vegetation collected between 1982 and 1990. Compiled map sources included soil surveys, regolith system maps, surficial geology maps, bedrock geology maps, topographic maps, and granular aggregate resource maps. Soil association polygons were inferred from compiled data. Some soil associations were modified from the central concept of recognized soil associations of New Brunswick (Fahmy et al 1986) in order to be directly interpretable as STs. For example, some shallow-to-bedrock soil associations were redefined as those showing bedrock within the upper 50 cm, rather than 1 m. STs were delineated on 1:50 000 base maps and digitized.

What remains to be done is essentially a GIS data-processing exercise. Vegetation types are estimated using algorithms developed from observed correlations between the provincial forest inventory map units (which denote species composition, development stage, and crown closure) and VT. When the midpoint of our VT-interpreted forest inventory polygons are intersected with the ST layer, we will have the means to calculate TU.

In spite of the possible information weaknesses in this process, we believe our maps to be acceptably accurate for many planning purposes related to wood supply analysis or silviculture. This process is now complete for all Crown lands. Maps will be updated with new information on a 5-year cycle to coincide with companies' revisions to their 25-year management plans as stipulated under the *Crown Lands and Forests Act*. Within the next planning cycle we anticipate (1) a revision of the forest inventory and (2) the acquisition of digital terrain maps, both of which should improve TU predictions from mapped resource information.

Verification

Testing of the site classification system is being conducted at both the stand and landscape levels. Observations of growth in managed stands were taken in 1989 and 1990 and are being compared with the stem analysis data from natural stands. Managed stand yield estimates will be revised using data from an inter-agency permanent sampling program (Upshall 1990).

At the landscape level, completion of the TU map database will permit analyses of the potential impact of site quality on yield from individual forests, given that we have now linked estimates of (1) the area of land in each site class and (2) a stratification of stands by development stage and species composition.

Other Work

Occurence of natural regeneration appears to be related to the species composition of pre-harvest stands and the condition of the overstory (Ruel 1989). In New Brunswick, natural regeneration of balsam fir and spruces is often prolific. Advance regeneration density estimates of spruce, balsam fir, and cedar (*Thuja occidentalis*) summarized by VT and included in the TU interpretation sheets were obtained from a cutover response project (Godin 1985, Zelazny 1987, Zelazny and Hayter (1991)). If the present site classification system is further developed to predict pre-harvest advance regeneration abundance, then we will be a step closer to integration of harvesting system, stand and site to achieve regeneration objectives.

A study has been undertaken by our staff to determine the effectiveness of the current site classification keys in young stands and cutovers. Preliminary results suggest that indicator species very rarely go to local extinction from areas disturbed by harvesting, although the relative post-harvest abundance of a species may be substantially changed when compared to its pre-harvest level.

Other agencies are also doing work that could eventually improve interpretations in the field guides. Forestry Canada-Maritimes is conducting growth and yield studies. A study of the effects of nutrient loss in biomass removal is underway by the same agency in co-operation with J.D. Irving Ltd. A study investigating the effects of different combinations of site preparation and TU on early survival and growth of planted black and white spruce is underway at the University of New Brunswick in co-operation with Fraser Inc. The Mineral Resources Branch of the provincial Department of Natural Resources and Energy has been mapping regolith systems in co-operation with the site classification effort for the past seven years. These data are valuable in improving the soils resource information.

Some TUs have little or no data for softwood productivity, and for some softwood species such as tamarack (*Larix laricina*) or Norway spruce (*Picea abies*) little productivity data exist and more sampling is needed. In addition, some forest companies rely heavily on the hardwood resource, yet growth and yield estimates by site for almost all hardwood species are only now starting to be collected for New Brunswick sites.

Acknowledgements

The authors are indebted to Drs. Louis Bélanger and Russell Wells for valuable comments on the original manuscript. Site classification efforts in New Brunswick have been a team effort, and we would like to thank all those involved over the years. Special mention to Drs. David MacLean and Herman van Groenewoud of Forestry Canada-Maritimes, and to representatives of New Brunswick marketing boards for making their data available for key testing.

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Ecological land survey in Quebec

by L. Bélanger[1], Y. Bergeron[2] and C. Camiré[1]

Summary

After a brief review of floristic classifications, ecological survey, as carried out in Quebec, is described. Three stages of development of ecological survey over the past twenty-five years are identified: (1) the pioneer work of Jurdant; (2) major ecological surveys from the late 1960s to the late 1970s; and (3) the diversification of the groups involved in ecological land surveys beginning in the 1980s, including universities, the Quebec Environment Department (MENVIQ) and the Quebec Department of Energy and Resources (MER). Intended for use in integrated land management, ecological survey must be an effective integrator of the various ecological evaluations; the information must be easily communicable and the methodology must be flexible. Ecological land classification has two dimensions: (1) taxonomic; and (2) cartographic. In the taxonomic units, the ecological region, the ecological type and the ecological phase are identified. In cartographic terms, local (ecological phase and type), regional (ecological system and subsystem) and national (ecological district and region) resolution is identified.

Quebec universities, MER and MENVIQ are presently involved in ecological land surveys. The new *Forest Act*, which was enacted in 1986 and which provides for sustainable yield and more intensive forest management, is a major force behind the promotion of the use of ecological inventories as the basis for management activities. Mapping of the ecological regions (1:1,250,000) has almost been completed in Quebec. Total coverage of the commercial forest as a function of ecological districts (1:250,000) could be completed within five years, and the mapping of ecological types (1:20,000) could be completed in 20 years at a rate of 10,000 km^2 a year. Although in the past ecological land surveys have been used primarily for environmental impact analyses (for instance, the installation of hydroelectric equipment and transportation corridors), the ecological framework is presently being used to prepare development plans for a number of regional county municipalities (RCMs). Pilot projects are under way to assess the potential applications of the ecological framework to forestry as part of intensive management efforts. Improvements are needed in both the accessibility of the information provided by the ecological framework (maps, site guides) and the development of interpretative tools for silvicultural measures.

Key words: ecological survey, ecosystem mapping, ecological land classification, forest ecology, forest site classification, Quebec.

Résumé

Après une brève revue des classifications floristiques, on présente l'inventaire écologique utilisé au Québec. On identifie trois périodes dans le développement de l'inventaire écologique ces vingt-cinq dernières années: (1) les travaux pionniers de Jurdant; (2) les grands projets d'inventaire s'étendant de la fin des années 1960 à la fin des années 1970; et (3) la diversification des intervenants débutant avec les années 1980 et impliquant le milieu universitaire, le ministère de l'Environnement (MENVIQ) et le ministère de l'Énergie et des Ressources du Québec (MERQ). Destiné à l'aménagement intégré du territoire, l'inventaire écologique doit être un intégrateur efficace des différentes évaluations écologiques; les connaissances doivent être facilement communicables et cela demande une souplesse méthodologique. On reconnaît deux dimensions à la classification écologique du territoire: la dimension taxonomique et la dimension cartographique. Parmi les unités taxonomiques, on note la région écologique, le type écologique et la phase écologique. Dans les unités cartographiques, on distingue les niveaux de perception locale (phase et type écologiques), régionale (système et sous-système écologiques) et nationale (district et région écologiques).

Le milieu universitaire québécois, le MERQ et le MENVIQ s'occupent actuellement d'inventaire écologique. La nouvelle loi sur les forêts adoptée en 1986, stipulant un rendement soutenu et un aménagement plus intensif des forêts, s'avère un élément déterminant d'accélération de l'inventaire écologique comme assise aux activités d'aménagement. La cartographie des régions écologiques (1/1 250 000) est presque terminée au Québec. D'ici cinq ans, la couverture totale de la forêt commerciale au niveau du district écologique (1/250 000) pourrait être terminée. Quant à la cartographie de type écologique (1/20 000), elle pourrait être réalisée en vingt ans à raison de 10 000 km^2 par année. Bien que par le passé la classification écologique ait surtout été utilisée pour l'analyse des incidences environnementales (comme la mise en place d'équipements hydro-électriques et de corridors de transport), on a recours en ce moment au cadre écologique dans la réalisation de schémas d'aménagement de certaines municipalités régionales de comté (MRC). Des travaux pilotes sont en cours afin d'évaluer les possibilités d'application du cadre écologique en foresterie dans le contexte d'un aménagement intensif. Des améliorations sont nécessaires tant au niveau de l'accessibilité des informations livrées par le cadre écologique (cartes, guides de terrain) que du développement d'outils interprétatifs pour les interventions sylvicoles.

Mots clés : cartographie des écosystèmes, classification des sites forestiers, classification écologique du territoire, écologie forestière, inventaire écologique, Québec.

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Une version française de cet article est disponible auprès de L. Bélanger.

Introduction

With an area of 1.67 million km^2, Quebec is the largest province in Canada. It can be divided into three ecological zones: (1) tundra; (2) taiga; and (3) forest (Figure 1). The forest zone (779,256 km^2) can be subdivided into hardwood forests, mixed forests and softwood forests. A number of ecological "domains" have been identified (Thibault and Holte 1985). These are geographic areas characterized by the same climactic vegetation on mesic sites.

In the hardwood forest subzone, the ecological domains are: (1) maple-hickory and maple-basswood; (2) maple-basswood and maple-yellow birch; and (3) maple-yellow birch. The climax associations of the corresponding ecological domains in the mixed forest are: (1) maple-yellow birch and fir-yellow birch; (2) fir-yellow birch; (3) yellow birch-fir; (4) fir-red maple; and (5) fir-white birch. The climax associations of the domains in the softwood forest are: (1) fir-black spruce; and (2) black spruce (Figure 1). The 545,700 km^2 of forest that is considered to be accessible and productive contain 4 billion m^3 of stumpage, 71% of which is softwood, 29% hardwood (Paillé 1987).

Until the late 1960s, Quebec's forest resources were considered to be more or less inexhaustible. Very little effort was made to take prompt measures to regenerate areas after felling or forest fires. Since 1980, more than 20 million m^3 of softwood have been harvested annually. The average gross annual increment of the entire exploitable softwood forest is 1.29 m^3/ha, while the average net annual increment is 1.03 m^3/ha, since insects reduce the annual increment by 7–9%, disease by 4–5%, natural mortality by 3–4% and fires by 2–3%.

The jobs of roughly 250,000 Quebecers are directly or indirectly related to the forest. Forest industries spend $2 billion in wages and salaries every year. The value of forest products totals close to $10 billion annually (over 8% of the GDP). The provincial and federal governments collect $2 billion in taxes annually.

With the observed increase in demand for wood products in the past 15 years, it has become clear that the forest industry will soon suffer stock shortages. Changes have to be made to our forest system requiring the forest industry to invest in forest management. In this context, a forest classification and particularly an ecological reference framework (ecological classification and mapping, interpretations and user's guides) become an interesting basis for silvicultural management practices.

Forest classifications in Quebec can be divided into two categories: (1) floristic classifications; and (2) ecological classifications. Grandtner and Vaucamps (1982) conducted a review of floristic classifications and provided an introduction to ecological classification.

After a brief review of the floristic classifications, ecological classification as used in Quebec is described. The requirements for an ecological classification are identified

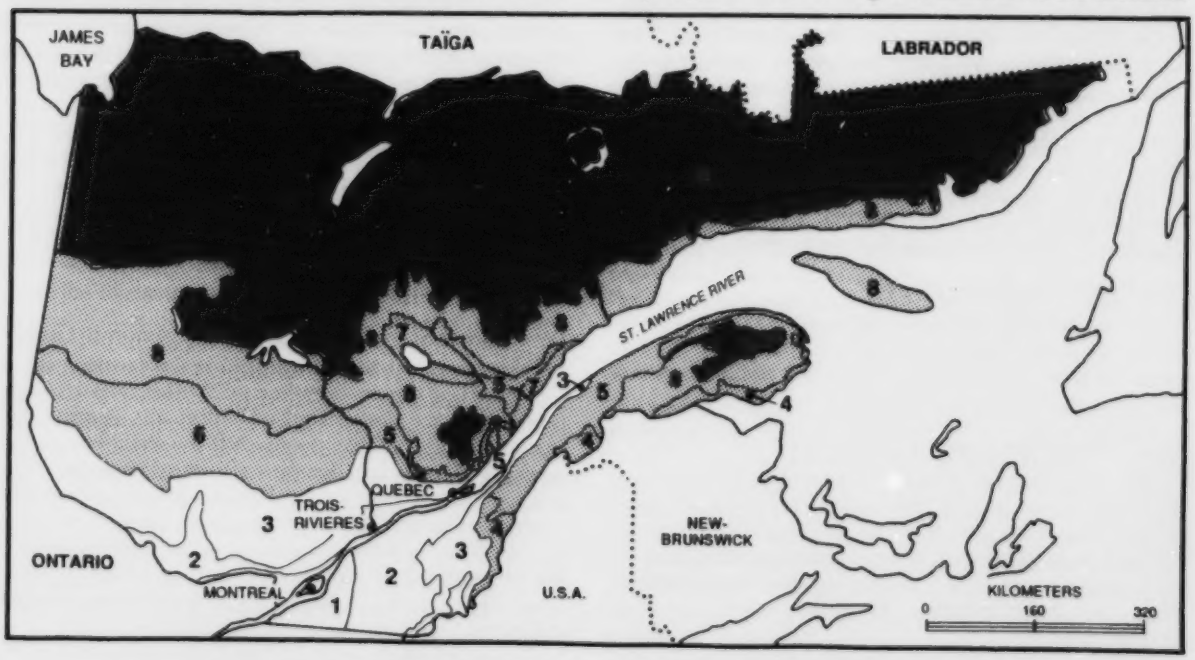

Figure 1. Forest zones and ecological domains in Quebec.

and the various stages of development of ecological survey in Quebec are outlined. The practical aspects of ecological land survey and classification are then discussed.

Floristic Classifications

Visits to Canada by Finnish phytosociologists Ilvessalo, Kujala and Cajander in the 1930s resulted in the introduction and adoption of Cajander's method (1909) for classifying forest types, which was based on undergrowth, by many Quebec foresters. Bellefeuille (1931), Rousseau (1931), Provencher (1931), Sisam (1938), Heimburger (1941) and Lafond (1956), to name a few, used this method to classify boreal forests. Rousseau (1944) and Lafond (1964) modified Cajander's method by including tree species.

Owing to the diversity and complexity of Quebec forests, particularly in areas further south, Linteau (1955) and Lafond (1964) adopted the phytosociological method of Braun-Blanquet from the Zurich-Montpellier school. This method covers all vegetation strata and includes quantitative observations. Based on the principle of characteristic species or characteristic groups of species, the Braun-Blanquet method makes it possible to define taxonomic units of plant communities. While using vegetation as the main criterion of classification, the method also makes use of edaphic and site factors as complements. Lafond and Grandtner, together with their graduate students from Laval University, worked with this method. Their work made a major contribution to our understanding of Quebec forests (Lafond 1964; Grandtner 1966; Blouin and Grandtner 1971; Brown 1981; and Blanchet 1982). Dansereau (1959) proposed a classification of plant associations based on their structure and floristic classification. Payette and Gauthier (1972) based floristic grouping on the vertical stratification of forest vegetation. More recently, work based on the ordination approaches developed by Curtis (1959) and Whittaker (1967) has been conducted (Bouchard and Maycock 1978; Gagnon and Bouchard 1981; Gauvin and Bouchard 1983).

Ecological Land Survey

Development of ecological survey in Quebec is characterized by three stages: (1) the pioneer work of Michel Jurdant; (2) major ecological survey projects; and (3) the diversification of the groups involved.

The Need for Ecological Classification

The development of an integrated ecological survey method in Quebec stems largely from changes in the way land and resource management were perceived. The problem consisted of developing an effective means of meeting new ecological information needs associated with intensive forest management and, more generally, integrated natural resources management.

With respect to forest management, Jurdant demonstrated in the early 1960s that the single-factor survey methods used up until then in Quebec were not fully satisfactory (Jurdant 1966, 1968). These methods, which used either vegetation or soil exclusively, could not answer all of the silviculturists' questions. Floristic classifications could not be used to evaluate the physical constraints of the environment on forestry activities, such as timber harvesting or construction of forest roads. Moreover, they were of limited use in areas disturbed by felling, which were the silviculturist's principal areas of intervention. As for the strictly pedologic classifications, they provided no indication of the response of vegetation to silvicultural treatments, the potential for regeneration after felling or the probable level of herb and shrub competition.

However, it was the promotion of integrated forest resources management (Jeffrey *et al.* 1970), with the introduction of such concepts as multiple-use forest management (Maldague 1966), integrated land zoning (Anonymous 1975) and ecological planning (Dansereau 1976; Bélanger and Pineau 1983; Domon *et al.* 1987a) that spurred the development of an ecological survey methodology. The objective was to provide the ecological basis considered essential to the success of integrated forest management. Multidisciplinary approaches, whereby specialists from various fields studied the same area simultaneously, each using survey methods proper to the particular field, posed a number of problems at both the practical and theoretical levels (Thie *et al.* 1979). The work of ARDA (Anonymous 1969), EZAIM (Dansereau 1976) or BAEQ (Eastern Quebec Development Bureau) (Grandtner 1968) revealed problems with this approach, particularly during final synthesis: overabundance of data, overlapping of map boundaries resulting in complex mosaics that were difficult to decipher, and disregard of the interaction among groups of variables. The need for an approach that would effectively integrate the various disciplines became apparent.

From an operational viewpoint, the objective was to produce a geographic reference framework that could be used to develop, on the basis of the same geographic contour lines, a set of interpretive documents covering potential biological productivity (forest, agricultural, wildlife), risks of disturbance or degradation of the environment (windthrow, erosion, landslide) and various other land capabilities (Gerardin and Ducruc 1979). In other words, the goal was to develop a truly integrated approach for the survey and analysis of natural resources. This method of ecological land survey is often referred to in French as "L'inventaire du capital-nature" (Jurdant *et al.* 1977).

Development Stages of Ecological Land Survey in Quebec

Three stages can be distinguished in the development of ecological land surveys over the past 25 years. The first stage is marked by the pioneer work of Jurdant. His objective was to develop a multi-factor approach to the classification and mapping of forest sites for the purposes of intensive forest management (Jurdant 1964a; 1964b; 1968). The proposed method, which was based in particular on the work of Christian (1952) in Australia and Hills (1961) in Ontario, proposed the delineation of "ecological types" or ecological units combining a geomorphologic type, a vegetation type and a soil series.

The second stage, from the late 1960s to the late 1970s, is characterized by major survey projects, such as those of the Saguenay-Lac-Saint-Jean area (25,000 km^2) (Jurdant *et al.* 1972); the James Bay area (425,000 km^2) (Ducruc and Bérubé 1980; Gerardin 1980; Jurdant and Ducruc 1980); Anticosti Island (15,000 km^2) (Desloges and Emond 1974); and the Lower North Shore area (100,000 km^2) (Ducruc 1985). The first of these surveys, that of the Saguenay-Lac-Saint-Jean region, was one of the pilot projects proposed by the National Committee on Forest Lands. It resulted in the

development of the first guidelines of the Canada Committee on Ecological Land Classification (Lacate 1969). In 1977, Jurdant *et al.* published *L'inventaire du capital-nature*, in which the methodology is described. At the provincial level, the committee on the application of ecology to land management proposed this approach as a methodological reference framework in a concern to standardize ecological data in Quebec (Jurdant *et al.* 1976). Ducruc (1979) has conducted a review of projects carried out in Quebec during this period.

The third period, which began in the 1980s, is characterized by a diversification of the groups involved both from universities (Bélanger *et al.* 1983; Bergeron *et al.* 1983; Bouchard *et al.* 1985; Waaub 1984) and governments (Thibault and Hotte 1985; Robert and Saucier 1987). A group of Jurdant's initial research team continues to conduct work at the Quebec Environment Department (MENVIQ) (Gerardin and Ducruc 1990a). Unlike the preceding stage, the survey projects are located mainly in inhabited regions of Quebec and frequently associated with the preparation of land development plans of the "Municipalités Régionales de Comté" (RCM). Moreover, Quebec's Ministry of Forests (MFQ) has undertaken a provincial program to complete the ecological classification of forests south of the 50th parallel (St-Laurent et Robert, 1990; Bergeron *et al.* 1992). The need for such a program has been stressed by the recent proposal of a new forest protection strategy based on an integrated pest and vegetation management approach (Anonymous 1991).

Practical Aspects of Ecological Survey

Although it can be used as a framework for analysis of the interrelationships between various components of the environment (Bergeron *et al.* 1983; Bouchard *et al.* 1985), ecological survey in Quebec has been developed primarily as a tool for integrated natural resource management. This method is thus similar to the ecological land survey approach as defined by Environment Canada (Anonymous 1981), which focuses on the effective integration of land assessment. Thus, the fundamental principle of practical usefulness of ecosystem classifications has always guided ecological land survey; a classification must be evaluated more for its practical value in terms of established objectives than strictly for its scientific value, which is always disputable, given the extraordinary complexity of the subject (Jurdant *et al.* 1977).

The objective generally sought by ecological land survey is to integrate the ecological dimension into the land management process by providing an ecological evaluation of a region and its resources. This integration reveals the potential offered and the constraints imposed by this environment, as well as the possible impact of various activities on the environment within a single geographical reference framework. The purpose of ecological survey is to provide the largest number of users of a given territory with organized information on the natural characteristics of the environment and to indicate its potential usages and resources (Ducruc 1986; Gerardin 1986). Since ecological survey is intended for integrated land management, it must allow for the evaluation of the potential of the land for various types of natural resource utilization.

Under integrated management, it must be possible to integrate the data on the resources of an area effectively. The ecological survey approach allows the evaluation of all potential uses as well as constraints on the basis of the same map contours. Their comparison and synthesis are therefore possible by simply overlaying the documents.

From the outset, ecological survey addresses the problem of information transfer. To be useful and used, the ecological data provided must be comprehensible to the various decision-makers involved in the management process. The scientific jargon of the ecological sciences must be translated into language understandable to non-specialists.

Since management problems vary with circumstances, the application of the methodological framework of ecological survey must be somewhat flexible, depending on the objectives sought and the environments studied. Thus the method is adapted to various levels of geographic resolution of the site, and to their corresponding map scales. The ecological survey method also allows flexibility in the level of detail of information, with the necessary level of precision corresponding to the required detail of management.

In response to these objectives and characteristics, the interpretation of ecological data have always formed an integral part of ecological survey. That is why proponents of this approach now refer to the ecological reference framework rather than to ecological mapping, which too often has restrictive connotations. An ecological reference framework includes all the documents that are needed to integrate the ecological dimension into the management process effectively. These include ecological classifications and maps, interpretations and users' guides. Ecological survey constitutes not just a data base, but a true ecological information system. It seeks to provide information to decision makers by providing, after the analysis of data, useful answers to their questions.

Such an ecological information system can be illustrated as three closely interwoven components (Figure 2): (1) the identification of ecological information needs; (2) the ecological classification, which provides baseline data; and (3) the ecological evaluation, which translates the data in terms of potential and constraints. The ecological land survey can therefore be considered an integrated ecological land evaluation as defined by the FAO (Anonymous 1984a).

Ecological Land Classification

As we have just stated, ecological survey comprises an ecological data base. This data base is structured by means of a classification procedure which seeks to give meaning to the complexity of the region by creating a system of land classes. Ecological Land Classification divides the area into "iso-ecological" units which are significant for management, that is, units characterized and named by the biophysical components that best reflect the utilization potential of the natural environment (Jurdant *et al.* 1977). Ecological survey produces a geographic reference framework (a map) which contains the ecological characteristics of the area (a classification). We will identify the conceptual basis on which this classification process is based and will then define the ecological units generally used by ecological survey.

Conceptual Basis

For the purposes of integrated natural resources management, the ecological data base required to conduct all necessary evaluations must be quite extensive. To produce these data, ecological survey has taken an integrated ecosystems

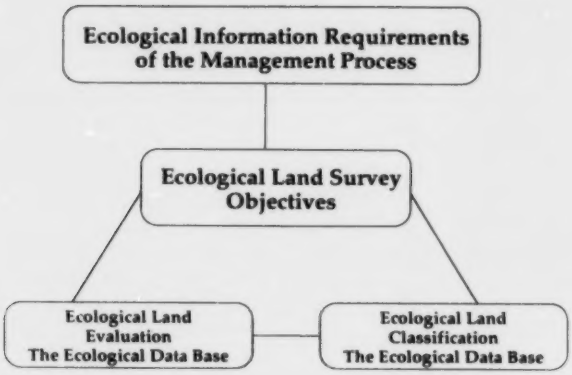
Ecological Information Requirements of the Management Process
Ecological Land Survey Objectives
Ecological Land Evaluation The Ecological Data Base
Ecological Land Classification The Ecological Data Base

Figure 2. Components of ecological land survey.

approach which uses *a priori* integration (Jurdant *et al.* 1977), so that all ecological variables are considered simultaneously under an integrative concept, the ecosystem. This type of integration goes beyond the simple graphic integration of overlaying sectoral documents. Such a multifactor classification can truly be called ecosystemic, since it is based on the study of relationships among various components of the environment.

Ecological survey uses an operational definition of ecosystem, stressing its effective delimitation. The ecosystem paradigm used is the geographic ecosystem, also called the landscape ecosystem (Rowe 1961, 1979; Anonymous 1981; Bailey 1981; Vink 1983; Bélanger 1985). This paradigm was proposed by Rowe as early as 1961. This pragmatic approach contrasts with more functional definitions of ecosystem, such as those of Odum (1971) or Dansereau (1976), who adopt an approach that stresses the functional aspects of the ecosystems.

The landscape ecosystem is defined as a delineated part of a territory having a certain degree of ecological coherence based on the physical, biological and anthropogenic criteria considered. These criteria are selected on the basis of the objectives sought. This geographic ecosystem constitutes, therefore, a landscape unit perceptible to any observer on the site or on aerial photographs (Veillette and Ducruc 1984a; Ducruc 1985).

The landscape ecosystem has generally been considered to be composed of two parts: (1) the land type, or the geosystem; and (2) its biological cover, the biosystem (Jurdant *et al.* 1977; Gerardin and Ducruc 1979). The land type covers the geological, geomorphological, topographical and edaphic characteristics of the area, whereas the cover depends on biological variables, including human activities (Ducruc 1985). More recently, it was proposed that a third component, the anthroposystem, be distinguished in order to integrate the human factor more effectively (Bélanger *et al.* 1983). A landscape unit would thus comprise three subsystems: (1) the geosystem, which defines the abiotic determinisms; (2) the biosystem, which determines biological production (vegetation, wildlife); (3) and the anthroposystem, which is expressed as the type of development of the area (Bélanger 1985).

To express the most active variables for each of these subsystems, an integrative concept can be associated with each of them. In 1972, Jurdant and his colleagues identified the soil as the best integrator of the active variables of the geosystem, and vegetation communities as the most sensitive integrator of the active variables of the biosystem. With respect to the anthroposystem, Bélanger (1985) proposed land use as the best integrator of the human factor. Figure 3 provides a structural diagram of the concept of landscape ecosystem, which is based on the diagram of the conceptual basis of Jurdant *et al.* (1977).

Ecological Units

In the past few years, it has been recognized that ecological land survey comprises two complementary dimensions: (1) a taxonomic one; and (2) a cartographic one (Gerardin and Ducruc 1979; Bélanger *et al.* 1983; Bouchard *et al.* 1985). In this sense, it differs from the approach proposed by Environment Canada, which is based exclusively on the cartographic dimension (Anonymous 1981).

In its taxonomic dimension, the survey approach establishes a typology of classification units based on an analysis of soil-vegetation-climate relationships conducted after sampling. There are several methods for determining the taxonomic units. The development of multidimensional analysis of ecological data (e.g. Legendre and Legendre 1983) has made it possible to integrate a statistical analysis of the interrelationships between the abiotic and biotic components in the process of determining the taxonomic units (Bergeron *et al.* 1985; Bouchard *et al.* 1985). By respecting the dominance of the discipline, however, the ecological survey often merely classifies taxa for each of the disciplines and performs an *a posteriori* synthesis, without a detailed analysis of the interrelationships between them. For instance, difficulties have been observed in the use of the taxonomic classification of soil in the context of an ecological integration (Bergeron *et al.* 1982; Lamontagne and Camiré 1987).

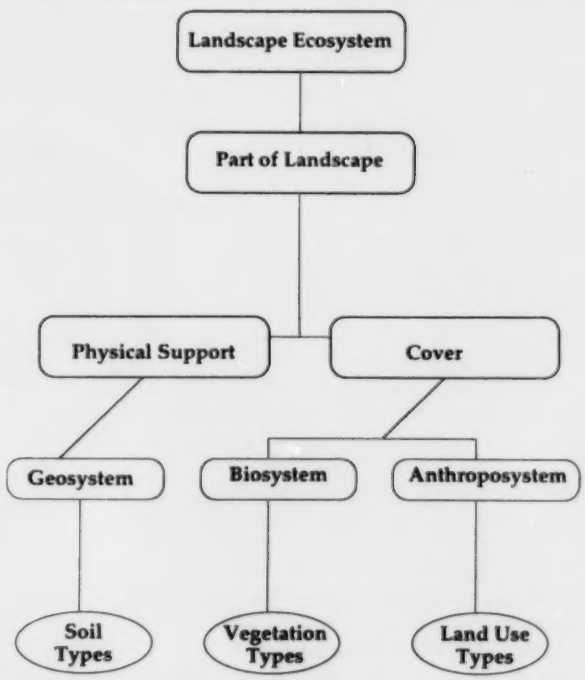

Figure 3. Landscape ecosystem as it appears in the ecological survey.

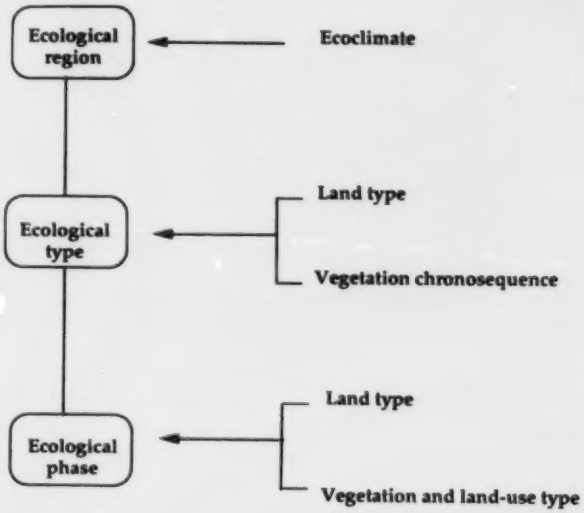

Figure 4. Ecological classification units.

In its cartographic dimension, ecological survey delimits the landscape units of a given area by isolating parts of a landscape on the basis of spatial patterns. Mapping may include taxonomic units, but it also includes mapping units in the strict sense of the term, using the regionalization approach (Bailey *et al.* 1978) whereby the landscape is subdivided into units on the basis of major ecological discontinuities.

Taxonomic units. Taxonomic units are the result of a typological analysis conducted by the abstraction of samples with similar properties into conceptual classes. These units are geographically independent since their classification is not linked to their location in a given area. Three taxonomic units are generally used: (1) ecological region; (2) ecological type; and (3) the ecological phase (Fig. 4). The main classification criteria for each are regional climate, soil and present site use, respectively (Gerardin and Ducruc 1979; Bélanger *et al.* 1983; Bouchard *et al.* 1985).

The **Ecological Region** is an ecoclimatic unit characterized by a distinct regional climate, particularly as reflected in the physiognomy, floristic composition or dynamics of the vegetation. In a given ecological region, under equivalent ecological conditions, the same vegetation chronosequences should be found. This unit can be considered a subdivision of the ecological zones (see Figure 1). The definition of this ecoclimatic framework is a prerequisite to the classification of ecological types and phases.

The **Ecological Type** can be defined as a unit within a given ecological region characterized by a particular land type for which one can infer a particular vegetation chronosequence. A land type is a unit where the physical support — unconsolidated material, soil drainage and topographic conditions — can be considered homogeneous. A vegetation chronosequence is the succession of vegetation types that may occupy a single physical support within an ecological region. The ecological type is a stable ecological unit which is edaphically, geotechnically and phytodynamically homogeneous. It may therefore serve as a basis for conducting homogeneous evaluations of current land potential.

The **Ecological Phase** is normally defined as a unit in a given ecological region which is characterized by a homogeneous land and vegetation type. In inhabited areas, this definition must be broadened to take into account environments that have been transformed by people. We can therefore define the ecological phase as a unit characterized by a homogeneous land type and type of occupation (vegetation or land-use). Unlike the ecological type, the ecological phase is a transitory unit. However, being homogeneous with respect to present occupation, it can serve as a basis for the assessment of current land potential.

Mapping Units. In its cartographic dimension, ecological land classification must subdivide the ecological continuum into landscape ecosystems. These units are generally produced by photo-interpretation supported by observation points made on the ground. The criteria used to perform this subdivision are related specifically to the map scale used and to the geographic extension of various ecological factors. At each level, it consists of acquiring the most detailed possible image of the landscape ecosystems (Ducruc 1985).

In terms of cartographic resolution, the ecological land survey establishes a hierarchical system in which the various levels of resolution of the site are defined, and themselves related to corresponding map scales (Table 1). The three principal levels of cartographic resolution can be differentiated as follows: (1) local, associated with large scales (1:5,000 to 1:25,000); (2) regional, associated with medium scales (1:50,000 to 1:125,000); and (3) national, associated with small scales (1:250,000 and less). In principle, there should be no overlapping of the cartographic boundaries of the various levels of resolution (Ducruc 1985).

Level of Local Resolution — The cartographic ecological phase and the cartographic ecological type form, respectively, the transitional and stable mapping units used at the level of local resolution. They are generally delineated by identifying discontinuities in one or more of the parameters considered (nature of unconsolidated material, the steepness and shape of slopes, the topographic location and soil drainage, vegetation and land use) on large-scale aerial photographs (greater than 1:20,000).

The cartographic ecological phase corresponds to a part of a territory, in a given ecological region, characterized by a particular ecological phase. Very large scales (1:10,000 or over) must generally be used to map disturbed and complex environments.

The cartographic ecological type is a portion of a territory in a given ecological region characterized by a particular ecological type. Unlike the ecological phase, the ecological type is a permanent ecological unit. It can generally be mapped at scales larger than 1:20,000.

Level of Regional Resolution — From a practical point of view, it is no longer really possible to map relatively uniform ecological types or phases by using an intermediate scale: it is simply too small. It is therefore necessary to produce map units that group together several ecological types and phases. For this, geomorphology is considered the most appropriate functional criterion (Jurdant *et al.* 1977; Rowe 1979). The ecological system, mapped at 1:125,000, is the unit which has most commonly been used for major survey projects in northern Quebec. At present, the scale of 1:50,000 appears to be preferred (Bélanger *et al.* 1983; Ducruc 1986).

Table 1. Ecological mapping units

Geographic level of resolution	Mapping unit	Mapping scale	Ecological factor
National	Ecological region	1 : 1,000,000	Ecoclimate
	Ecological district	1 : 250,000	Physiography
Regional	Ecological system	1 : 125,000	Geomorphology
	Ecological subsystem	1 : 50,000	Topography
Local	Ecological type	1 : 20,000	Soil
	Ecological phase	1 : 10,000	Vegetation and land use

The ecological system is a part of a territory individualized as a stable landscape unit. It can be distinguished by the morphology of the physical support due to a particular combination of the geology, the relief, unconsolidated material and hydrography, which infer an ordered distribution of ecological types (Ducruc and Bérubé 1980). Given the scales traditionally associated with the ecological system (1:100,000 to 1:250,000), the mapping units form complex landscape units as defined by Lacate (1969), units composed of several unconsolidated materials of different origins. At 1:50,000, however, it is frequently possible to map simple landscape units, which are homogeneous in terms of the origin of the unconsolidated materials.

In addition to the geological, topographical and hydrological criteria used to differentiate ecological systems, the current site condition can also be considered. Such a unit is therefore similar to the traditional concept of landscape by integrating both the stable physical support and the current biological and anthropogenic cover of the site. This unit, which Bélanger (1985) calls the ecological subsystem, can be defined as a part of a territory individualized as a current landscape unit; it is distinguished by a specific combination of geology, relief, unconsolidated materials and hydrology, and by a certain development of the site, as observed in terms of its present cover and land use in the past. A scale of 1:50,000 appears appropriate for this level of ecological resolution.

Level of National Resolution — At a small scale (less than 1:250,000), two units are most often used: (1) the ecological district; and (2) the cartographic ecological region. The ecological district can be defined as a part of a territory characterized by a particular geology and physiography. The cartographic ecological region corresponds to a part of a territory characterized by distinct ecological responses to the regional climate expressed by a particular complex of ecological types.

Current Status and Development Prospects

As we have seen, the conceptual basis and methods required for the implementation of the Quebec ecological framework are quite elaborate. Some degree of consensus has been reached among the various government and university groups involved. The two main ecological mapping programs presently under way at the Ministry of Forests (Thibault and Hotte 1985; Robert and Saucier 1987; St-Laurent and Robert 1990; Bergeron *et al.* 1992) and at the MENVIQ (Ducruc 1986; Gerardin and Ducruc 1990a) use the different units of the ecological framework. In addition, the methodological approach is now taught at several Quebec universities, and a number of research projects based on this approach are now under way. Moreover, the need for an ecological framework as a basic tool for forest management and development in Quebec has been clearly illustrated (Brown 1983; Gerardin 1986). In addition, owing to the lack of data on Quebec's forests, a committee responsible for preparing a report on the status of research and development in the Quebec forestry sector recommended that ecological mapping programs be stepped up (Anonymous 1983).

The lack of an adequate forest ecology framework became clearly apparent after the recent shortages of wood supplies, which are expected to become serious at the turn of the century (Anonymous 1984b). This problem, linked primarily to an unsuitable harvesting method, underutilization of all wood production and the lack of intensive forest management, has been aggravated by the recent spruce budworm (*Choristoneura fumiferana*) epidemic. This realization led to the development of a new forest policy (Anonymous 1984b) and, in 1986, to a new forestry act (*Forest Act* 1986, c 108). By introducing the concept of sustainable yield, this act forces Quebec foresters to undertake an intensive forest management program (Paillé and Deffrasnes 1988). It has become clear that in this context, the use of the information provided by ecological surveys is essential.

Two important points of consensus emerge from this brief overview of the situation in Quebec. First, it appears that the methodological approach leading to the development of the ecological framework is well established among the various groups working in Quebec, although fine-tuning may still be necessary. Second, more and more groups are recognizing the need for the ecological framework as a forest management and planning tool. However, Ducruc's observation (1979) that the uses of existing ecological surveys are sporadic is still true, particularly in the area of forest management.

The various ecological classification projects conducted have been used mainly for environmental impact analyses, such as the work conducted in the James Bay region as part of the installation of hydro-electric equipment and transportation corridors (Gantcheff *et al.* 1979; Fortin and Legendre 1982). With respect to forestry, the projects conducted at James Bay were used mainly to conduct a survey of forest resources (Jurdant 1975). More recently, the ecological framework was used to prepare development plans for Regional County Municipalities (Veillette and Ducruc 1983, 1984b; Bélanger 1985; Bouchard *et al.* 1985; Guilbault 1985). The development plans are limited, however, to a general evaluation of the potential and to the zoning of sites as a function of priority uses. Although forestry potential is taken into account, the ecological framework is not integrated into the forest resource management and planning at this level.

In forest management, although the foresters are aware of the importance of the information provided by the ecological framework, the information is still little used as a stratifier of forest activities (Belanger et al. 1990). The forest stand still constitutes the basic unit of silvicultural treatment, regardless of the ecological characteristics of the site. The lack of large-scale site maps (1:20,000) partially explains the limited use of ecological mapping. Available maps cover small areas and their scales vary. The ecological mapping programs presently being conducted at the Ministry of Forests should remedy this problem. In fact, 12,500 km^2 have already been mapped at the ecological type level (1:20,000) and 360,000 km^2 at the ecological district level (1:250,000) in representative ecological regions (Bergeron *et al.* 1992). The entire commercial forest of Quebec should be mapped at the ecological type level within the next 20 years at an annual rate of 10,000 km^2, while a complete coverage of the ecological districts could be completed within five years (D. Robert, pers. comm.). The ecological regions of almost the entire province of Quebec have already been mapped (Gerardin 1980; Thibault and Hotte 1985).

Recently, pilot projects designed to integrate the ecological framework with the forest management and planning process have been undertaken in regions where studies on ecological classification and mapping have been conducted (for instance, the last management plan of the Montmorency forest, Laval University's experimental forest (Bélanger *et al.* 1988)). Moreover, Veillette and Gerardin (1985) have provided interpretations of ecological mapping at 1:50,000 conducted in the Gaspé region for forestry purposes. Harvey and Bergeron (1987) have undertaken a project aimed at applying an ecological classification of the Abitibi region to intensive forest management. Recently, ecological classifications conducted specifically for forest management have been undertaken on the North Shore and the Appalachian regions (Grondin 1990, 1991).

In addition to biases as to the practical usefulness of ecological data, the use of ecological surveys in forestry faces two problems which hinder the transfer of data. First, the data are often presented in a form not accessible to the users. Map legends are too often overly complex and the scales used do not meet the users' needs. To make the data accessible, identification guides for the ecological units on the site should be prepared. In addition to facilitating the relationships between ecological classification and mapping and the concrete knowledge of the site, these guides could be used to complement the ecological map when specific information is necessary. Moreover, such guides would make it possible to accelerate the use of the ecological framework where no ecological map is available. Gerardin and Ducruc (1990b) have developed an identification guide on deposits and soil drainage for the RCM of Rouyn-Noranda, and Harvey and Bergeron (1987) have prepared a key to the identification of ecological units for two townships in northwest Quebec.

Another obstacle to the use of the ecological framework is that few interpretation keys for ecological units in relation to silvicultural practices have been developed. Jurdant and his colleagues (1977) describe a set of possible interpretations in the context of forestry: these include forest productivity, the presence of competitive species after felling, and potential for the use of machinery. However, there exist relatively few applied research projects which address the evaluation of silvicultural practices as a function of the ecological variables of the sites. In addition, the few existing projects are often stratified as a function of forest stands and references to the characteristics of the sites are often difficult to interpret. As a result, evaluation keys are lacking and existing keys have not been validated.

Fortunately, in recent years, there appears to be a growing interest in the development of projects to bridge the gap between the ecological framework and interpretations for forest management. Gagnon and Marcotte (1980) and Majcen *et al.* (1984) have conducted projects on forest productivity which are stratified on the basis of the ecological framework. Research is also underway on the impact of ecological variables on the abundance of advanced growth in Quebec's softwood forests (Ruel 1990; Marchand 1990; Côté and Bélanger 1991). Harvey and Bergeron (1989) have studied regeneration and competition after felling as a function of the various ecological units, and Durand *et al.* (1988) have evaluated the effect of the type of site preparation on the abundance of competitive species. Work on the selection of species to be reforested and the type of plantation maintenance based on the ecological framework is underway at the Centre d'enseignement et de recherche en foresterie (CERFO) in Sainte-Foy (Cauboue 1988), at the Laurentian Forestry Centre (L. Archambault pers. comm.) and as part of a joint project by the University of Quebec at Montreal and the University of Montreal (Gagnon *et al.* 1987).

More generally, data from ecological surveys have served as a stratifier for more fundamental studies on forest ecosystems. Relations between stand vulnerability to spruce budworm outbreaks and site characteristics have also been established (Archambault *et al.* 1990; Gagnon and Chabot 1988; Dupont *et al.* 1991). Similarly, it has been possible to evaluate the incidence and intensity of maple decline on the basis of the ecological classification conducted in the Appalachians region (Roy *et al.* 1985). Bergeron *et al.* (1988) have studied secondary successions as part of the ecological classification of the RCM of Haut-Saint-Laurent. Using the same classification, Domon *et al.* (1987b) examined the present use and farmers' interpretation of their forest site. They were then able, by using ecological classification, to compare these results with the potential of the sites for the production of wood material.

These different projects are examples of the current use of the ecological framework. Over the next few years, the development of an organized hierarchy of research within the framework will permit a more effective dissemination of research results. This would make research results available for the purposes of forest management more quickly.

Conclusion

This overview of ecological classification in Quebec brings to light three important stages of development. The first, the period preceding the 1970s, is characterized primarily by a concern to integrate data on the ecological variables of the sites into silviculture. The second, which roughly covers the 1970s and 1980s, is characterized by major ecological surveys which resulted in important methodological and conceptual developments. Since then, various research groups have focused primarily on applying ecological classification to the evaluation of the potential and allocation of resources under the legislation creating RCMs, and more recently to

forest management and planning. In light of the changes in the forest policy and the intensification of ecological mapping activities in forests, future developments should focus primarily on forest management. The success of applied experiments will be crucial to the development of generalized and operational use of ecological data in the management and planning of forest resources.

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Québec forest ecological classification program

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Abstract

In 1986, the ministère des Forêts du Québec instituted a provincial program to study forest ecosystems entitled the "Forest Ecological Classification (FEC) Program." Under this program, a multidisciplinary team was charged with conducting ecological surveys, analyzing and characterizing the variables of the physical environment, classifying vegetation and preparing integrated forest inventory maps. Their goal is to complete the ecological classification of the forests in all territories south of the 52nd parallel. To undertake such a vast project, it was necessary to prepare detailed methodological guides for data collection, data analysis and mapping. The following products are now available for many different ecological regions: classifications of forest types, toposequences, physiographic and surface deposit maps and integrated forest inventory maps. Multivariate analysis methods are used in analyzing ecological data; in this way, hierarchical classifications and ordinations can be used as the basis for identifying and describing forest types, vegetation-physical environment relationships and successional patterns. Such ecological classification products are an indispensable tool for forest managers and users.

Key words: ecological classification, forest ecology, forest management, forest site classification, multivariate analysis, physical environment, Québec.

Résumé

Dès 1986, le ministère des Forêts du Québec a mis sur pied un programme provincial de connaissance des écosystèmes forestiers nommé «cadre écologique forestier (CEF)». Une équipe multidisciplinaire est responsable de la réalisation de travaux d'inventaire écologique, de classification de la végétation, d'analyse et de caractérisation des variables du milieu physique, et de cartographie écoforestière intégrée. Ce programme vise à compléter la classification écologique du territoire pour l'ensemble des forêts au sud du 52e parallèle. L'ampleur d'un tel mandat a nécessité l'élaboration de guides méthodologiques détaillés de prise de données, d'analyse des données et de cartographie. Les produits suivants sont désormais disponibles pour nombre de régions écologiques : classifications des types forestiers, chênes de sols, cartes du relief et des dépôts de surface et cartes d'inventaires forestiers intégrées. Les méthodes d'analyse multifactorielle sont utilisées dans l'analyse des données écologiques. Ainsi, la classification des types forestiers, les relations végétation-milieu physique et les formes de succession sont élaborées à partir des ordinations et des classifications hiérarchiques. Ces produits de classification écologique constituent un outil indispensable pour l'aménagement et l'utilisation du milieu forestier.

Mots clés : aménagement forestier, analyse multifactorielle, classification écologique, classification des sites forestiers, écologie forestière, milieu physique, Québec.

Introduction

After the adoption of the *Forest Act* in 1986, the gouvernement du Quéebec implemented a new forest policy based on the principles of protection, multipurpose use and sustained yield. Guided by these principles, the ministère des Forêts du Québec (MFO) is striving to improve forest management practices and optimize forest production for timber, wildlife and recreation opportunities. To achieve these goals, it was necessary to initiate a provincial program to study forest resources under the auspices of the Service des inventaires forestiers (SIF). This program focuses on the study and classification of forest ecosystems and the evaluation of their dendrometric characteristics. This paper will summarize the ecological classification activities that fall within the scope of the "Québec Forest Ecological Classification (FEC) Program" and the principles on which they are based.

Since 1986, a multidisciplinary SIF team made up of foresters, biologists, geomorphologists and a pedologist has been responsible for conducting standardized ecological forest surveys, characterizing the principal ecological variables (physiography and surface deposits), determining the relationships between vegetation and the physical environment and classifying the forest vegetation. The principal intended use for the FEC Program is to provide information and tools to field-level managers which will guide them in selecting and applying forest management systems and silvicultural techniques. In Québec, forest management decisions are to be guided by a knowledge of the composition, structure and functions of forest ecosystems to ensure sustained yield and multipurpose forest use. Thus it has become a matter of vital importance to understand the forest's regenerative capacity and the successional behaviour and pattern of ecosystems after disturbances due to both natural (i.e. fire, insect infestation) and human causes (i.e. harvesting). Knowledge of forest ecosystems is also necessary for selecting the species best adapted to the environment and those which can achieve higher yields.

The classification results are expressed under the Québec hierarchical system of ecological land classification (Jurdant *et al.* 1977). This ecosystematic classification system, which integrates all the physical and biological components of a land area, has been widely applied in the Canadian provinces (Thie and Ironside 1977), the United States (Bailey 1976; Wertz and Arnold 1972) and Australia (Christian and Stewart 1968). In Québec, the concepts of ecological region, ecological district, ecological type and phase (previously developed by Jurdant *et al.* 1977) are widely applied in ecological land surveys involving universities (e.g. Bélanger *et al.* 1983, Bergeron *et al.* 1983, Bouchard *et al.* 1985), the MFO and the ministère de l'Environnement du Québec (MENVIQ) (Bélanger *et al.* 1992). The MENVIQ ecological framework (Ducruc 1986, Gérardin and Ducruc 1990) serves as a basis for the preparation of land development plans of the "municipalités régionales de comté." The hierarchical structure of ecological land classification applied in the MFO's FEC program is presented in Figure 1.

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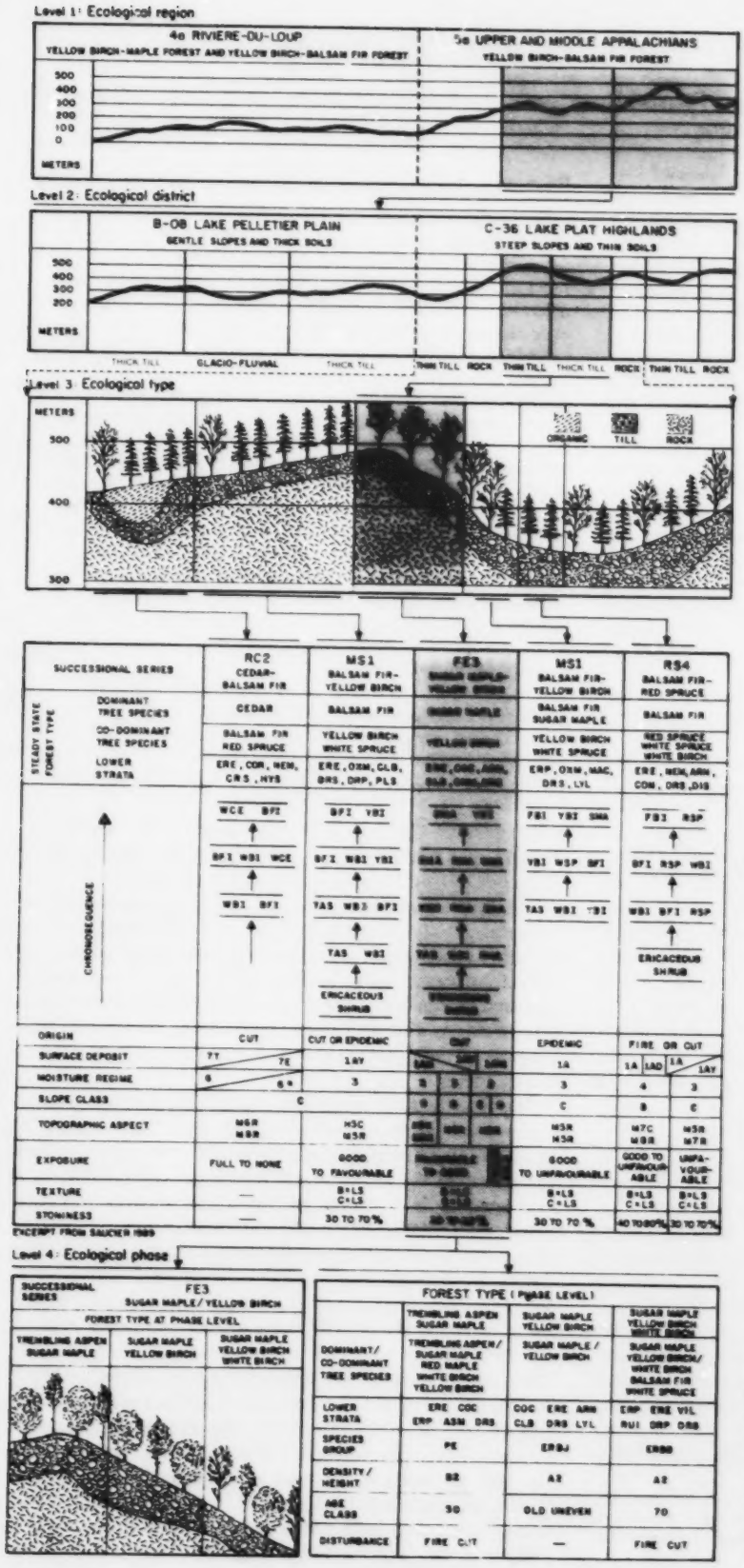


Figure 1. Québec's hierarchical structure of ecological land classification. Four classification levels have been defined. An equivalent number of mapping scales correspond to these levels: region, district, type and phase. A synthetic example of toposequence is shown at level 3. Level 4 describes the species composition and stand characteristics of forest types at the phase level. These results are part of the forest ecological classification of 5a-Basses et Moyennes Appalaches ecological region (Saucier 1989). Acronyms and codes used in this figure are described in Robert and Saucier (1988).

The analytical concepts, methods and algorithms used in the classification work are based on the analytical procedures most commonly used in forest ecology in Canada (especially Ontario: Jones *et al.* 1983, Sims *et al.* 1989). Vegetation and vegetation-physic~l environment relationships are analyzed through the use of multivariate numerical methods (Hill 1979a, ter Braak 1987). All stages of the FEC program are computerized. Field microcomputers are used for on-site data collection and microcomputers are used for on-site data collection and microcomputers are used for data processing and analysis.

Ecological District

To understand the nature and distribution of vegetation within ecological regions (i.e. a segment of land characterized by a distinctive regional climate as expressed by the vegetation; Jurdant *et al.* 1977), a survey of the biotic and abiotic features is required. To map certain crucial abiotic features which constitute the physiographic components of southern Québec we selected the second level of Jurdant's ecological land classification (Jurdant *et al.* 1977): the ecological district. An ecological district is defined as a "portion of land characterized by a distinctive pattern of relief, geology, geomorphology and regional vegetation" expressed at a scale of 1:250,000. Defined this way, it corresponds to the "land district" of Lacate (1969) and resembles the "site district" of Hills (1959). At this level, the factors that delimit mapping units are the characteristics of the physical environment. Vegetation cannot serve as a discriminant feature for delimiting mapping units: this conclusion is shared by Damman (1979) and Jurdant *et al.* (1969). Ecological systems and subsystems also assist in the mapping of the regional topography and geomorphology (Bélanger *et al.* 1991).

After several years of experimentation in various regions of Québec, we have developed a cartographic method specifically designed for describing and mapping ecological districts (Robitaille 1988) that includes a relief classification adapted to Québec's land area (Robitaille and Saucier 1989). To date, nearly 360,000 km^2 of a total 652,000 km^2 in southern Québec have been mapped. Several different ecological regions have been defined in the process (Figure 2). Ecological district maps at a scale of 1:250,000, surface deposit maps at 1:50,000, district data bases, physical environment characterization summaries and field guides for the identification of surface deposits have been produced.

Ecological Survey

Within each ecological region, ecological surveys are conducted to define the composition, structure, and spatial dynamics of the forested ecosystems. To standardize the data collection procedure, a rigorous methodology was developed. It ensures objective, non-biased data representative of the environment's variability throughout the ecological region. Since 1986, sample collection at more than 14,000 sampling plots (the basic unit) has been carried out (Figure 3). Sampling standards are established in a document entitled "Normes de prises de données et de vérification" (Robert and Saucier 1988). The ecological survey covers 270 000 km^2 in hardwood, mixed and boreal forest zones (after Thibault 1985).

Methodology

Working from a preliminary photo-interpretation of the vegetation, the data collector plots a transect line across a representative topographical segment of a district. Six temporary sampling plots (400 m^2) are positioned along the

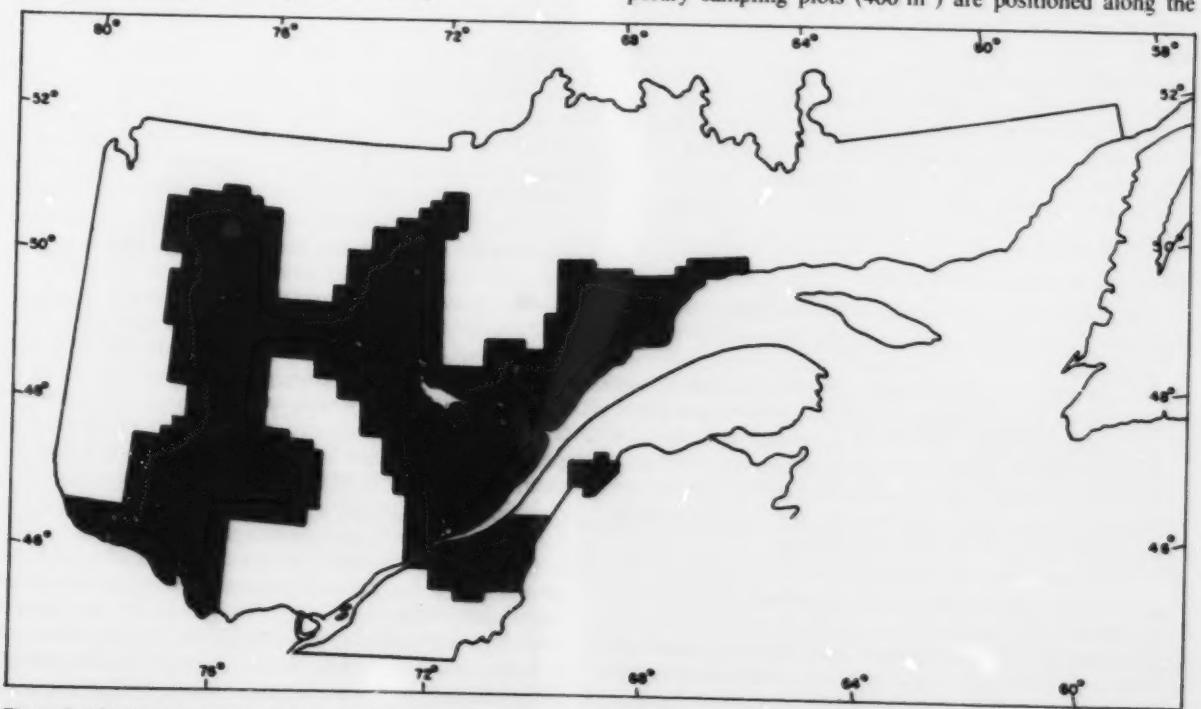


Figure 2. Mapping of ecological districts (1:250,000) and surface deposits (1:50,000) in southern Québec. The dark areas have both ecological district and surface deposit maps.

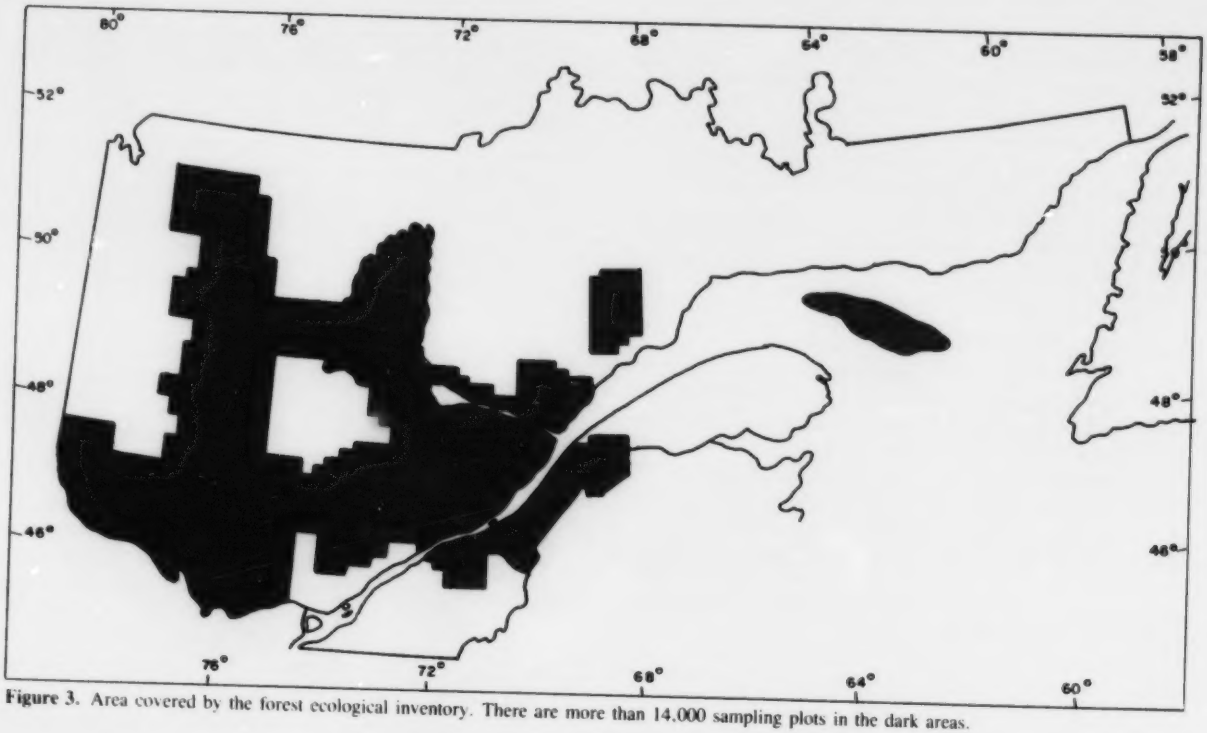


Figure 3. Area covered by the forest ecological inventory. There are more than 14,000 sampling plots in the dark areas.

transect line, which is less than 1.5 km in length. The sampling intensity is one plot per 15 km^2 for the hardwood forest zone, one plot per 20 km^2 for the mixed forest zone and one plot per 25 km^2 for the boreal forest zone. Each plot is described in terms of its topographical, geomorphological and soil characteristics (52 abiotic variables in total), vegetation structure and species composition. On-site data collection is carried out by SIF forest technicians and by consulting firms contracted by SIF. To ensure the highest degree of precision, collected data are audited by a team of SIF forest technicians and foresters. Then vegetation and physical environment data are stored in data files on a microcomputer (Figure 4).

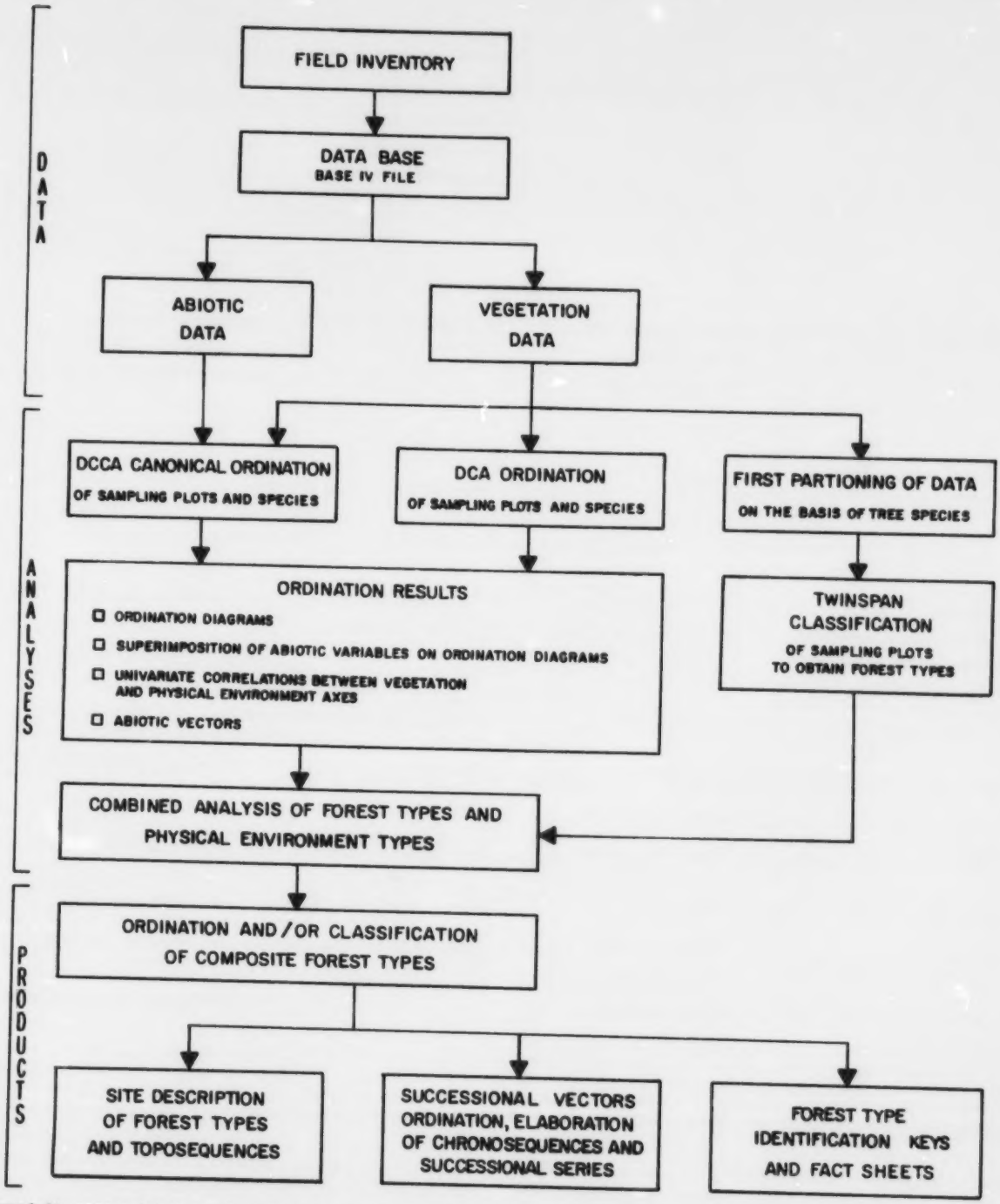
Forest Ecosystem Classification

Activities pertaining to classification of forest types have a number of specific objectives. These are outlined below.

- Development of forest type classification. A forest type (vegetation type) is characterized by the homogeneity of its overstory and understory species and by the homogeneity of its structure and physiognomy. A forest type occupies sites whose abiotic characteristics are confined to known limits. It possesses its own successional dynamics and a particular distribution.
- Definition of the relationships between the significant abiotic variables and forest vegetation, as well as production of autecological analyses.
- Characterization of the physical environment associated with each forest type, especially for variables important to forest managers: moisture regime, surface deposit, slope, topography, exposure, texture, stoniness and terrain roughness.
- Development of chronosequences and successional series for related forest types.
- Development and production of management interpretations required by forest managers and users (e.g. field guides to the identification of forest types).

The use of multivariate numerical analysis methods is preferred because it eliminates the subjectivity inherent in non-numerical methods. The methods selected also make it possible to process a great number of sampling plots (800-1000) within a short time. The stages of classification analysis are illustrated in Figure 4. The DCA (derived from the DECORANA program, Hill 1979a) and DCCA (derived from the CANOCO program, ter Braak 1987) ordinations organize the sampling plot and species data statistically to explain species variability within forest types. These ordinations are also used to detect the principal abiotic gradients as expressed by the observed variability in vegetation. The TWINSPAN hierarchical classification method (Hill 1979b) is then used to group sampling plots that share similar species composition. The forest types so defined are presented within a hierarchical structure in which each forest type has a distinct overstory and understory species composition, in addition to being defined by a set of indicator species. The classification results are expressed by forest type identification keys or classification dendrograms (Figure 5).

By comparing ordination and classification results, we have been able to refine the definition of forest types, since the abiotic conditions of each type are known. At this stage, forest types derived from the TWINSPAN classification may be further subdivided on the basis of abiotic conditions. When TWINSPAN divisions are too numerous or do not have ecological significance, the resulting groups can be amalgamated. Site conditions associated with each forest type can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OF SAMPLING PLOTS AND SPECIES
FIRST PARTIONING OF DATA
ON THE BASIS OF TREE SPECIES
ORDINATION RESULTS
ORDINATION DIAGRAMS
SUPERIMPOSITION OF ABIOTIC VARIABLES ON ORDINATION DIAGRAMS
UNIVARIATE CORRELATIONS BETWEEN VEGETATION AND PHYSICAL ENVIRONMENT AXES
ABIOTIC VECTORS
TWINSPAN CLASSIFICATION
OF SAMPLING PLOTS TO OBTAIN FOREST TYPES
COMBINED ANALYSIS OF FOREST TYPES AND PHYSICAL ENVIRONMENT TYPES
PRODUCTS
ORDINATION AND/OR CLASSIFICATION OF COMPOSITE FOREST TYPES
SITE DESCRIPTION OF FOREST TYPES AND TOPOSEQUENCES
SUCCESSIONAL VECTORS ORDINATION, ELABORATION OF CHRONOSEQUENCES AND SUCCESSIONAL SERIES
FOREST TYPE IDENTIFICATION KEYS AND FACT SHEETS

Figure 4. Vegetation and physical environment data analysis in relation to development of forest types, successional series and vegetation-physical environment relationships. (DCA/DCCA = detrended correspondence analysis; detrended canonical correspondence analysis.)

be represented by various simple techniques. In addition to histograms illustrating the distribution of abiotic parameters for each forest type, toposequences (Figure 1, level 3) were also developed. Toposequences (''sères physiographiques'') illustrate the distribution of potential steady-state forest types along a topographic gradient. These steady-state forest types are identified as potential climax associations in Daubenmire's forest habitat-type classification (Daubenmire 1952). Within this graphic representation, variables such as altitude, surface deposit, stoniness, texture and moisture regime are also represented.

Let us define chronosequence and successional series next. A chronosequence, as a part of a successional series, is the entire progression of seral stages or phases from a pioneer

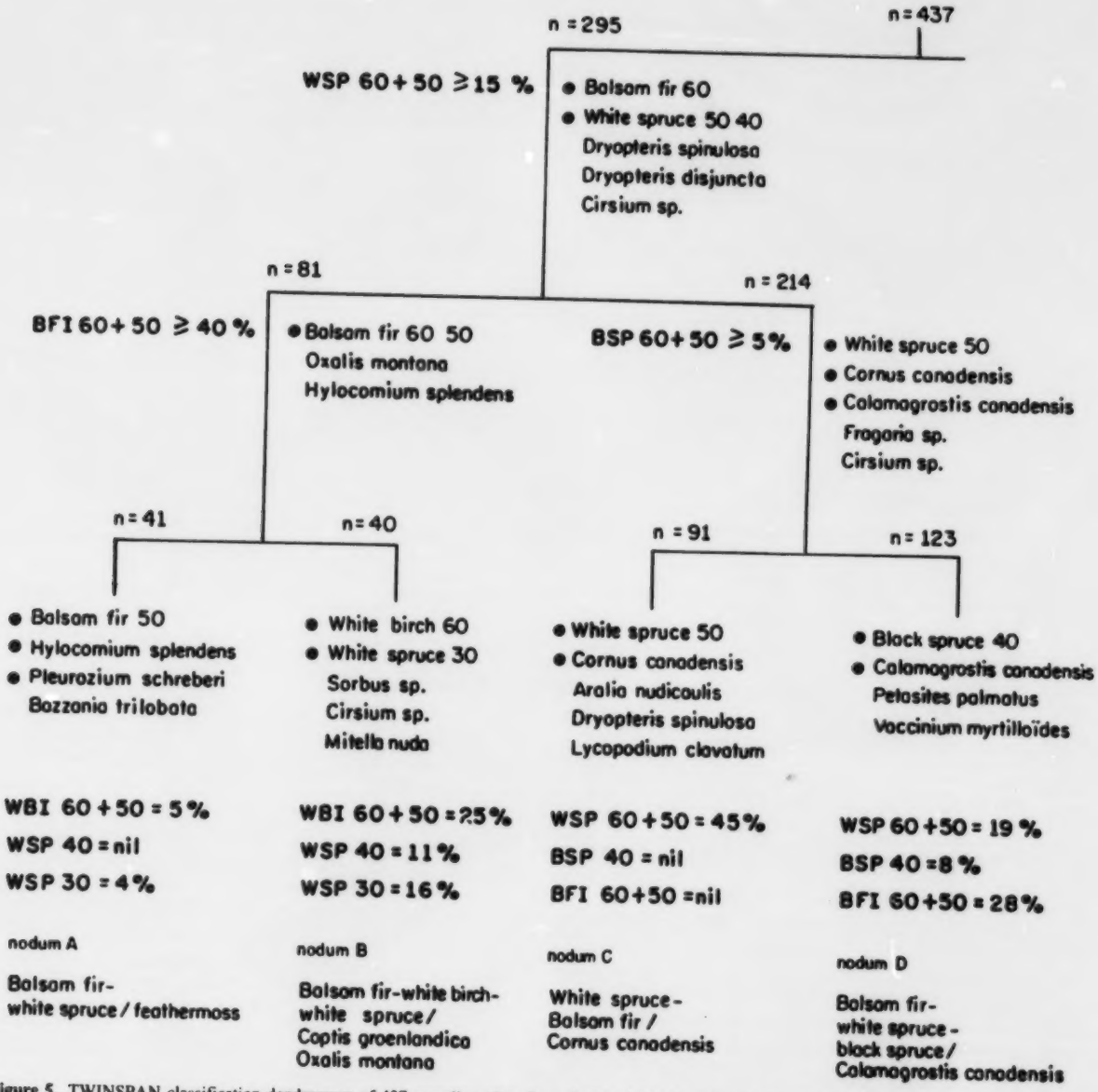


Figure 5. TWINSPAN classification dendrogram of 437 sampling plots from Anticosti Island (only the left part is shown). The number (i.e. 60, 50, 40, 30) accompanying each tree species indicates a tree height class. 60 corresponds to the ≥ 12 m height class; 30 corresponds to the ≤ 1 m height class (regeneration). Among the preferential species, the ones with a dot (·) correspond to indicators. Tree species acronyms in bold character correspond to dominant species that help the identification of a forest type or nodum on the dendrogram. BFI, BSP, WSP, WBI stand for balsam fir, black spruce, white spruce and white birch respectively. These results are part of the forest ecological classification of the 10a-Anticosti ecological region (Bergeron 1992a).

vegetation type to a steady-state vegetation type. A chronosequence may also follow a retrogressive and a cyclic pattern. A successional series ("série évolutive") pools together chronosequences (and their respective vegetation types) that lead to the same steady-state forest community (or forest type), as defined in terms of tree species composition and physiognomy. According to Rey (1960) and Ozenda (1964), a successional series (or "série de végétation") groups vegetation types linked in the same chronosequence either progressively or retrogressively.

Daubenmire (1952) defines a series as a group of habitat-types with the same dominant climax species, a habitat-type being a part of the landscape supporting particular climax associations. The use of the term "successional series" in this paper follows these concepts.

Chronosequences forming a successional series can be found in association with various site conditions and may be related to different disturbances. The chronosequences of the same series share the same range of moisture regime conditions, i.e. xeric, mesic or hydric. A DCA ordination applied solely to tree species (after Goff and Zedler 1972) enables us to establish successional vectors (Figure 6) which are translated into chronosequences (Figure 1, level 3). An understanding of the abiotic conditions associated with chronosequences helps us define the series subsequently.

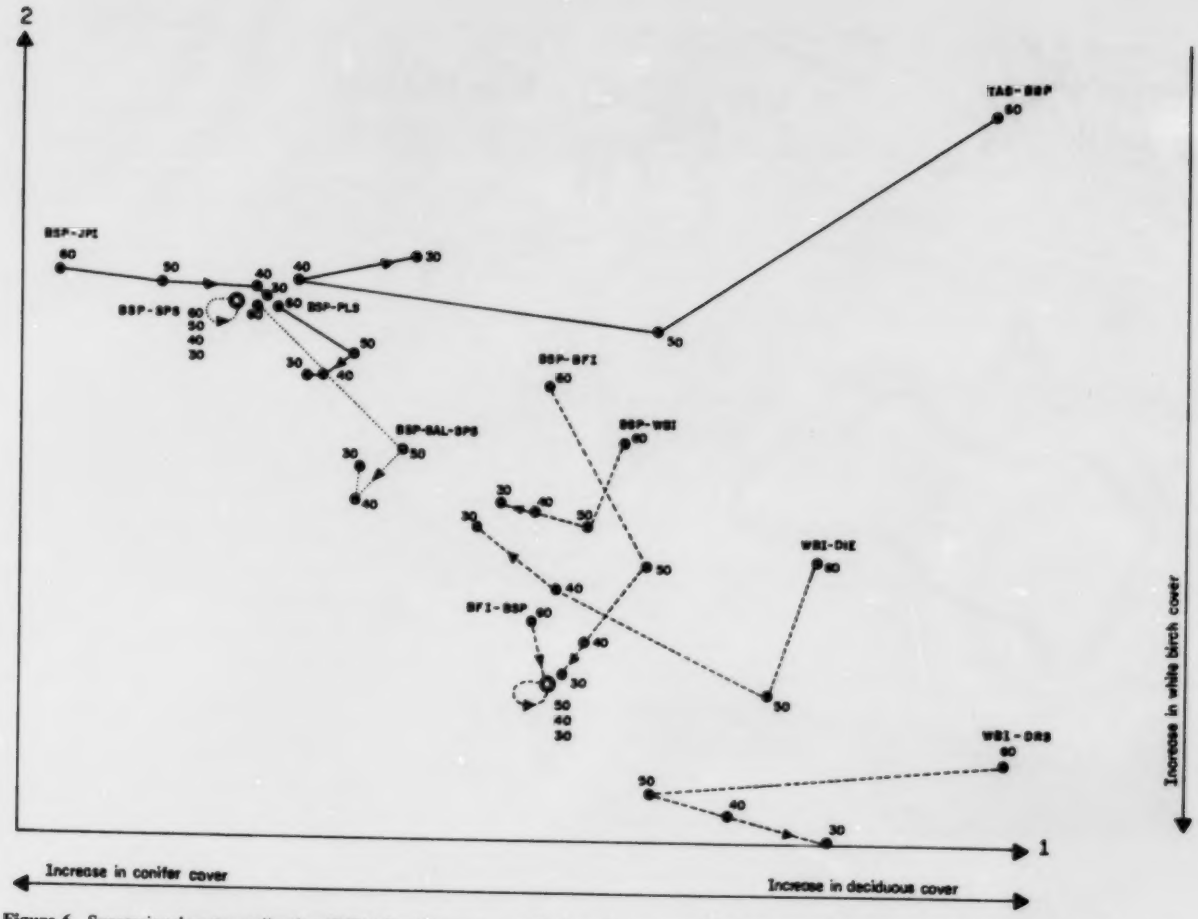


Figure 6. Successional vector ordination (DCA) for 10 forest types. Each vector represents a forest type and each number (i.e. 30, 40, 50, 60) represents its height class (60 stands for the ≥ 12 m class 30 the ≤ 1 m class or regeneration). Forest types are identified by dominant species acronyms: BFI = balsam fir; BSP = black spruce; DIE = *Diervilla lonicera*; DRS = *Dryopteris spinulosa*; JPI = jack pine; PLS = *Pleurozium schreberi*; SAL = speckled alder; SPS = *Sphagnum* sp.; TAS = trembling aspen; WBI = white birch.

Forest types BSP-SPS and BSP-SAL-SPS are grouped in the black Spruce/*Sphagnum* — RE3 successional series; BSP-JPI, TAS-BSP, BSP-PLS are grouped in the black spruce/feathermoss — RE2 successional series; BSP-WBI, BFI-BSP, BSP-BFI, WBI-DIE, WBI-DRS are grouped in the black spruce balsam RE-5 successional series.

These results are part of the forest ecological classification of 12b-lac Chibougamau ecological region (Bergeron 1992b).

The various ecological classification products developed through this process are combined in the integrated forest inventory map ("carte éco-forestière") at a scale of 1:20,000 (Figure 7). This map represents the final product of the FEC program. The production of these maps involves the following steps: photo-interpretation of the stand; interpretation of geomorphological features (surface deposits, moisture regime, slope); and interpretation of successional series. Stand and ecological photo-interpretation is conducted by means of 1:15,000 infrared aerial photographs. The mapped polygons from the aerial photographs are then transferred onto a 1:20,000 base map. To verify the accuracy of integrated forest inventory maps, a ground-truth procedure is carried out. This map consists of homogeneous mapping units which are annotated with information on several variables : surface deposit type and thickness, soil drainage, slope class, successional series and forest stratification (Figure 7). Recently the SIF has begun to investigate applications of the ecological classification. Interpretive maps have been developed at a scale of 1:20,000 for themes such as reforestation, spruce budworm vulnerability and deer habitat management.

Conclusion

The most important parameters characterizing the forest types encountered in an ecological region are summarized in a technical report that provides an ecological overview of that ecological region (e.g. *La Végétation forestière de la région écologique Sa-Basses et Moyennes Appalaches*: Saucier 1989). In this document, forest types are described by fact sheets highlighting the FEC products presented above. The first parameters described are the forest type physiognomy and species composition, with an emphasis on dominant and indicator species. These are identified in the forest type identification key. All the environmental variables are described on the fact sheets for each forest type. Histograms and ordination diagrams are used for this purpose. The successional status of each forest type is discussed,

Figure 7. Integrated forest inventory map at a scale of 1:20,000. This excerpt is taken from the 31 I/11 N.E. map sheet. Mapping units ——— \\ ——— delineate homogeneous forest stands and corresponding site characteristics. Each mapping unit or polygon is characterized by an ecological type designation and a forest stratification. Two mapping units (A and B) highlighted in the map are described.

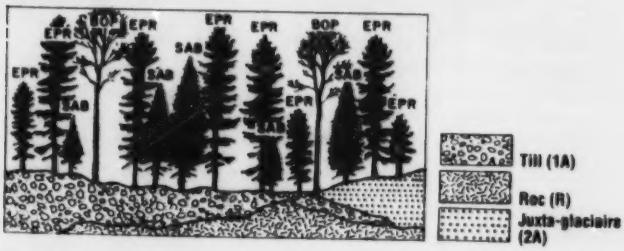
	A	B
Ecological type	1AY2 C FE32	1AY3*C MS1
Deposit: ■ type ■ tickness ■ moisture regime	Glacial till (1AY) 50-99 cm (1AY) 2	Glacial type (1AY) 50-99 cm (1AY) 3 with seepage (*)
Slope	8-15 % (C)	8-15 % (C)
Successional series	Sugar maple - yellow birch FE32	Balsam fir - yellow birch MS1
Forest stratification	ErBj B2 Vin	BjR(F) C2 Vin
Species group[1]	ErBj : Sugar maple : 33-66 % Yellow birch: 33-50 %	BjR(F) : Yellow birch: 51-75 % Conifer : 26-50 % Balsam fir and wite spruce
Density / height	60-80 % / 17-22 m (B2)	40-60 % / 17m-22m (C2)
Age class	Old uneven (Vin)	Old uneven (Vin)

1 Based on basal area

4A-RS42-5.3 EPR / PLS VAM

Pessière à épinette rouge / mousses, Vaccinium

Région écologique:	4A	Collines de Mégantic, lac Etchemin
Série évolutive:	RS42	Sapinière à épinette rouge typique
Stade évolutif:	5.3	État soutenu
Nombre de relevés:	35	



Composition en espèces

Strate arborescente (70 - 95%)
Dominantes: Picea rubens[6]
Compagnes: Abies balsamea[1]
Sporadiques: Betula papyrifera+

Strate arbustive

Commerciale (30%)
Dominantes: Abies balsamea[3]
Compagnes: Picea rubens[1]
Sporadiques: Betula papyrifera+
Acer rubrum+

Non-commerciale (30%)
Dominantes: Vaccinium myrtilloides[2]
Kalmia angustifolia[1]
Compagnes: Nemopanthus mucronata[1]
Viburnum cassinoides[1]
Sporadiques: Amelanchier sp.+

Strate herbacée (25%)
Dominantes: Cornus canadensis[1]
Compagnes: Pteridium aquilinum[1], Clintonia borealis[1], Chiogenes hispidula[1],
Sporadiques: Trillium undulatum[1], Epigea repens[1]
Maianthemum canadensis[1], Gaultheria procumbens+,
Pyrola secunda+

Strate muscinale (40 - 75%)
Dominantes: Pleurozium schreberi[4], Dicranum sp.[4]
Compagnes: Ptilium crista-castrensis[1], Bazzania trilobata[1],
Sporadiques: Sphagnum girgensohnii[1]
Hylocomium splendens+, Polytrichum sp.+, Cladina rangiferina+

Figure 8. Fact sheet describing the red spruce, moss, *Vaccinium* forest type. This example is part of the FEC field guide prototype developed for the Appalachian region, ecological regions 3e, 4a, 5b (Grondin *et al.* 1991). The forest type number contains the following information: ecological region, 4A; sucessional series and successional stage, RS42-5.3; overstory dominant species and indicator species, EPR/PLS-VAM.
The following forest type attributes are illustrated:
- stand structure (diagram);
- species composition: tree layer, shrub layer, herbaceous and moss layer (**strate arborescente, arbustive, herbacée, muscinale**);
- soil characteristics, including surface deposit, drainage, texture, stoniness, roughness (**dépôt, drainage, texture, pierrosité, rugosité**);
- topographical features, including slope position, exposure, altitude and slope class (**situation and versant, exposition, altitude, pente**);
- soil type (**type de sol**);
- humus type (**type d'humus**);
- distribution (**distribution**);
- successional status (**dynamisme**);
- species group (**strates forestières**); and
- remark (**remarque**).

Acronyms and codes used in this figure are described in Robert and Saucier (1988).

Type forestier **4A-RS42-5.3 EPR / PLS VAM**

Milieu physique

Caractéristiques / Dépôt	Drainage 1	2	3	4	5	6	Texture	Pierrosité (%)	Rugosité
R	⊕						—	50 - 60	3 - 4
M1A	⊕								
1AM		⊕							
1AY			⊕				B:LS/C:LS	30 - 60	3
1A			●	●	●				
1AD					⊕			>70	3 - 4
2A			⊕	⊕			B:SL/C:S	30	2
3AN					⊕		B:LS/C:LS	10	1

Légende
○ < 1%
⊕ 1 à 10%
◔ 10 à 20%
◑ 20 à 40%
◕ 40 à 60%
● > 60%

Topographie

Situation / Versant	Sommet/ haut de pente	Bas de pente	Mi-pente	Terrain plat/ replat
Haut				
Moyen	◔	◡	◑	●
Bas				

Exposition:

Altitude: 260 à 410m

Pente: B^5, A^3, C^2

Types de sol: PHFGL[7], PHFO[1], GO[1]
Types d'humus: Mor[9] (10 ± 4cm), tourbe[1] (20 ± 5cm)
Distribution: Fréquent dans l'ensemble physiographique U - Coteaux des Basses-Appalaches
Dynamisme: Type forestier d'état soutenu qui peut se régénérer par le feu. Suite aux coupes ou en l'absence de perturbation, il peut évoluer vers la sapinière à épinette rouge, mousses et Vaccinium. Ce type forestier provient de feu ou de coupe. Il peut également être issu d'une dégradation de la sapinière à épinette rouge, mousses et Vaccinium, à la suite d'une épidémie de tordeuse des bourgeons de l'épinette.
Strates forestières: E E
Remarque: Dans la strate arborescente, l'épinette rouge est parfois remplacée par l'épinette noire.

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with an emphasis on stand origin, related disturbances and successional pattern. The forest type distribution within each ecological region is also examined.

Toposequences, initially developed to aid ecological photo-interpretation for mapping purposes, are now being used by field foresters to help them identify the forest stands that can be expected to develop after harvesting given certain site conditions. Toposequences are also useful for harvesting, stand improvement and reforestation planning purposes. The integrated forest inventory and interpretive maps based on the products described above constitute a multipurpose silvicultural tool. Identification of ecological variables on a 1:20,000 scale provides a planning tool that helps foresters to select better and more appropriate silvicultural treatments on the basis of a comprehensive knowledge of the forest environment. The use of these integrated forest inventory maps, ecological district (1:250,000) and surface deposit (1:50,000) maps, in combination with the toposequences, helps forest managers solve problems involving road network establishment, identification of sensitive sites, stand vulnerability to spruce budworm, etc.

Quebec's FEC system differs in a number of ways from other previously developed classification approaches. It integrates all the ecological variables to create a comprehensive FEC program. Because of the vast size of Quebec's forests (652 000 km^2), the SIF has also developed a high level of technical expertise in ecological survey work. More than 60 technicians and professionals from the Service as well

as private-sector consulting firms participate in ecological surveys each year. Detailed methodological guides and analytical procedures which are applicable to any other forested land area have been developed to treat and analyze large amounts of detailed and often complex data (Saucier *et al.*, in preparation).

Current initiatives involve the incorporation of forest productivity data into the FEC to determine the productivity of ecological types. The information contained in the FEC of specific ecological regions constitutes a basis for the development and production of FEC and management interpretation field guides. Prototypes of both types of field guide have been developed for the Appalachian region (Grondin *et al.* 1991). Two pages from the FEC field guide prototype illustrating the forest type fact sheets are reproduced in Figure 8. On a broader level, the MFO is currently developing geographic information systems (GIS) which will link together forest inventory, forest ecological classification, wildlife, landscape and hydrographic components into a unified information system. These activities are a part of Québec's integrated resource management project. This program, involving several ministries concerned with resource management, incorporates the use of the FEC, which provides data and interpretations on forest ecosystems (Anonymous 1991). The wide range of ecological classification products described in this paper makes it possible to meet the many needs related to forest ecosystem management in Québec.

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The current status of forest site classification in Ontario

by R.A. Sims[1] and P. Uhlig[2]

Abstract

Forest sites are diagnostic forest-landscape ecosystem units that resource managers must deal with during the planning and implementation stages of management. Forest sites are the basic building blocks for undertaking integrated resource management which weighs wildlife, recreation, environmental impact and various other concerns along with timber harvesting. Consequently, accurate and practical systems for classifying and mapping forest sites are becoming increasingly necessary to organize, communicate and use existing and new management knowledge and experience effectively.

Over the past four decades in Ontario, a number of studies and resource surveys have provided important background information on forest sites. Many have considered, to varying extents, the integrative roles of vegetation, soil-site, landform and general climate on forests and forest land. Generally, the emphasis has been on description and classification, with results generating a better understanding of how various forests in different areas develop, both qualitatively and quantitatively, in relation to soil-site or other features of the basic land resource. Some of these studies and surveys have been instrumental in advancing the definitions and understanding of forested ecosystems. Others have provided new information on site dynamics, interrelationships and functions, or have contributed to the science (and art) of site evaluation and classification.

This paper briefly summarizes the current status of forest site classification in Ontario. Over time, the role of forest site classification has evolved in response to new technologies and information, and to new emphases and values in resource management. In general, site classification research has become increasingly integrative and quantitative. Some of the important future challenges facing forest site classification in Ontario are briefly discussed.

Key words: ecological land classification, forest ecology, forest ecosystem classification, forest management interpretations, forest site classification, land use planning, Ontario.

Résumé

Les sites forestiers sont les unités diagnostiques de l'écosystème forestier ou paysager dont on doit tenir compte lors de la planification et de l'exécution d'un projet d'aménagement des ressources. Les sites forestiers servent de base à un aménagement intégré des ressources, tenant compte à la fois de la faune, des activités récréatives, des retombées environnementales, de plusieurs autres facteurs et de la récolte du bois. Il est par conséquent de plus en plus important de disposer de systèmes de classification et de cartographie des sites forestiers qui soient pratiques et précis afin d'augmenter et de mieux organiser, communiquer et utiliser notre connaissance et notre expérience en matière d'aménagement.

Durant les quarante dernières années, un certain nombre d'études et d'inventaires des ressources ont fourni des renseignements généraux importants sur les sites forestiers. Ils ont souvent intégré, à divers degrés, les rôles joués par la végétation, le sol et le site, les formes de relief et le climat sur les forêts et le territoire forestier. En général, on mettait l'accent sur la description et la classification, ce qui permet de mieux comprendre comment des forêts se développent, qualitativement et quantitativement, dans différentes régions, suivant les caractéristiques du sol ou du site, et d'autres éléments propres au terrain. Plusieurs de ces études et inventaires ont servi à mieux définir et à mieux comprendre les écosystèmes forestiers. D'autres ont fourni des renseignements nouveaux sur la dynamique, les corrélations et les fonctions des sites, ou bien ils ont permis de faire progresser la science (et l'art) de l'évaluation et de la classification des sites.

Cet article donne un bref aperçu de la classification des sites forestiers en Ontario à l'heure actuelle. Avec le temps, la classification des sites forestiers a vu son rôle évoluer pour répondre aux nouvelles technologies et connaissances ainsi qu'à un changement de priorités et de valeurs dans le domaine de l'aménagement des ressources. De façon générale, la recherche en matière de classification des sites va de plus en plus vers l'intégration et le quantitatif. L'article aborde certains des défis importants auxquels l'Ontario devra faire face en matière de classification des sites forestiers.

Mots clés : classification de l'écosystème forestier, classification des sites forestiers, classification écologique du territoire, écologie forestière, interprétations de l'aménagement forestier, Ontario, planification de l'utilisation des terres.

Introduction

Forest sites can be viewed as basic building blocks for undertaking integrated resource management, a process which weighs wildlife, recreation, environmental impact and various other concerns along with timber harvesting. They are diagnostic stand-level forest-landscape ecosystem units that resource managers must recognize and deal with appropriately during the planning and implementation stages of management. Consequently, accurate, consistent and practical systems for classifying and mapping forest sites are essential so that existing and new scientific knowledge and management experience can be organized, communicated and applied effectively. Moreover, a clearer knowledge of forest sites at the stand level provides an important basis for a better understanding of the processes and ecosystem relationships that exist and interact at broader landscape levels.

A variety of studies and resource surveys have provided information on forest sites in Ontario. Many have considered, to varying extents, the integrative roles of vegetation, soils, landform and general climate on forests and forest land. Some have given direction to the landscape-level interpretation of

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land patterns, and to the use of mapping to address problems of multiple land-use planning at a variety of scales. Others have focused on the stand level, emphasizing site description and classification. Some of these stand-level studies have resulted in a much clearer understanding of the ecological dynamics of various forest sites. Collectively, these landscape-level and stand-level investigations have generated a better understanding of how various forests in different areas develop, both qualitatively and quantitatively, in terms of soil, landform, climate and other land resource features and values. These studies and resource surveys have been instrumental in refining the science (and art) of site evaluation and classification, within and outside of Ontario.

This paper summarizes progress in forest site classification research over the past 40 years, and briefly describes the current status of forest site classification in Ontario. Over time, the role of forest site classification has been modified in response to new technologies and information, as well as to changing roles, responsibilities and emphases in resource management. Approaches to forest site classification in Ontario have evolved continually in recent years as our needs, perspectives and social values have shifted, and as our experience and scientific understanding have increased. In general, forest site classification in Ontario has become increasingly comprehensive, integrative and quantitative.

Landscape-level Studies

Originally, forest site research in Ontario was undertaken to meet a need for accurate, descriptive resource maps. There was a strong interest in developing techniques and methodologies that could be employed to evaluate resource values critically, so that the most appropriate land-use activities could be matched with individual land units. This early form of ecologically oriented land survey was based on a philosophy of multiple land-use which ranked forestry objectively as a land use in relation to other potential uses such as recreation, wildlife habitat, or agriculture. Such an approach has considerable merit, and is consistent with current emphases on integrated resource management and sustainable forest management.

G. Angus Hills (1902-1979) was a pioneer of the ecological approach to understanding and describing forest sites in Ontario (Jacobs 1979). Hills initiated forest site-related research in Ontario during the 1940s, drawing on his extensive practical experience in pedology and soil mapping, as well as a thorough understanding of contemporary European approaches to landform description, plant sociology and forest mensuration. During the 1950s and 1960s, Hills and his colleagues, working at the provincial Department of Lands and Forests, developed what was referred to as the "Ontario Site Classification System" (Hills 1952, 1953, 1954, 1958, 1960, 1961; Hills and Pierpoint 1960; Hills *et al.* 1970). This hierarchical classification was designed to stress physiographic characteristics of sites and was organized as a multi-level framework for forest management information (Figure 1).

At the broadest level, Site Regions were based on the observation and interpretation of vegetation-landform coincidences which also expressed major zonations of the macroclimate continuum (Figure 2a,b; Hills 1960). Hills (1953) described Site Regions as broad geographical zones within which specific plant successions occur on specific landform

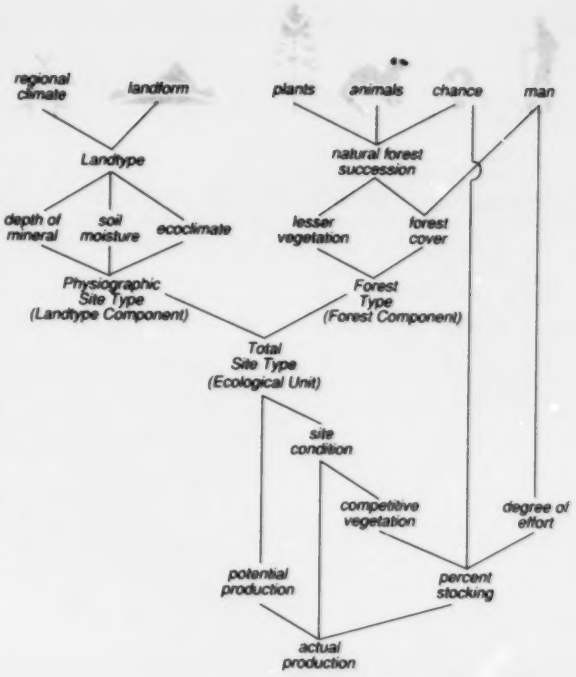

Figure 1. Some of the interrelated components described by Hills' Ontario Forest Site Classification; this chart shows how the system stresses physiographic characteristics and ecological relationships which influence forest production (after Hills 1961).

positions. The detailed taxonomic level of the typical forest stand (the so-called "Total Site Type") consisted of two components: the "Physiographic Site Type" and the "Forest Type", both of which were characterized by specific physical and vegetational features (Hills 1958; Hills and Pierpoint 1960; Hills *et al.* 1970). Physiographic Site Types were defined by narrow ranges in the depths of geological materials within the rooting zone, the soil moisture regime and the local climate. Forest Types were defined as a specific combination of overstory tree species and understory vegetation species occurring repeatedly on similar physiographic conditions at the same stage of forest succession within a given Site Region (Hills and Pierpoint 1960). "Landtypes" were also featured prominently in Hills' classification. Landtypes, defined as landforms within a given Site Region that exhibited narrow ranges of soil texture and mineral composition within the normal rooting depth of trees, were often used as a primary mapping unit (Hills and Pierpoint 1960; Figure 1).

At all levels, Hills' classification dealt with the recognition of mapping units at appropriate scales. A number of reference area survey programs using the system were conducted during the late 1950s and early 1960s. Individual studies were undertaken to demonstrate the applicability of Hills' approach to multiple-use planning, with mapping units and subsequent interpretations based on the inherent biological capability of the landbase. Investigations were performed on areas of various sizes ranging from as small as approximately 50 km^2 (Lynn and Zoltai 1965) to entire administrative Districts (Hills 1963; Keenan and Hills 1964) and Regions (Zoltai 1965, 1974) which cover 10,000 km^2 or

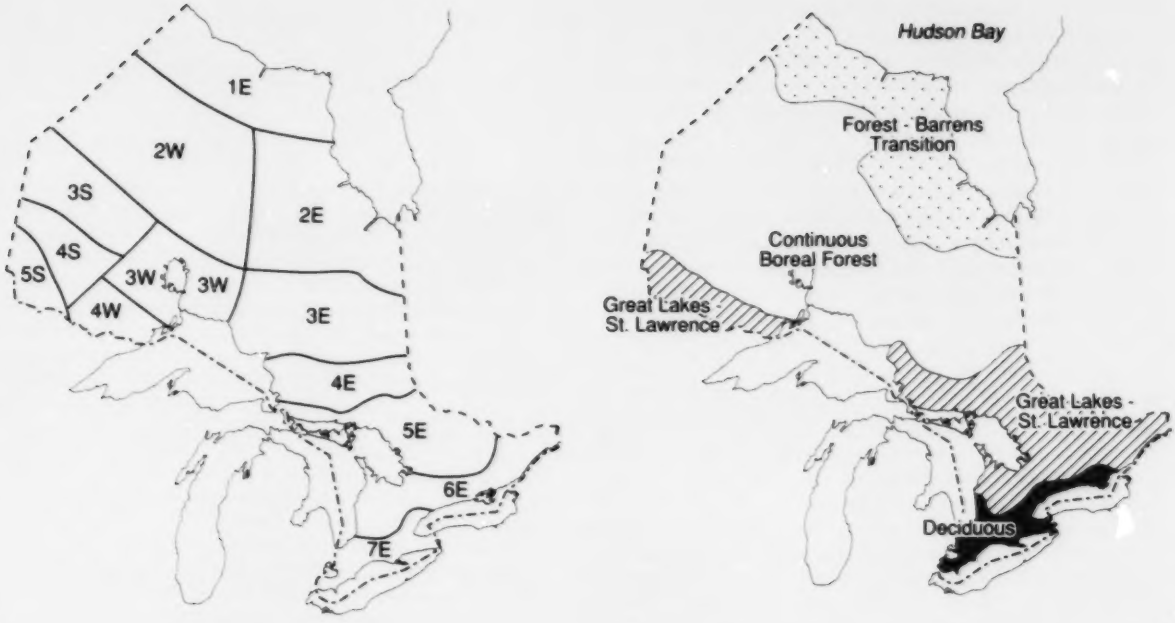

Figure 2. Maps of Ontario showing regional breakdowns: (left) Physiographic Site Regions (Hills 1953, 1960), (right) Forest Regions (Rowe 1972).

more. A primary emphasis in these reference area studies was the characterization of landtypes and their configuration through an integrative treatment of physiography, soils, climate and vegetation (Burger 1972a). In most of these reference area studies, greater importance was placed on describing physiography and soils rather than vegetation, although vegetation clearly had its place in the overall classification framework.

In many instances, the development of resource maps was augmented by a systematic analysis and ranking of land capability or potential for forestry, agriculture and appropriate levels of economic development (Hills 1942; Hills and Pierpoint 1960; Pierpoint 1962; Pierpoint and Hills 1963). This exercise required careful definition and use of detailed and innovative mapping procedures, and the derivation of relatively complex capability or suitability rankings (Hills 1960; Pierpoint and Hills 1963). The comprehensive land-use plans and interpretive maps developed for the Glackmeyer Development Area (Hills *et al.* 1960) and Tweed Township (Keenan and Hills 1964) are excellent examples of multiple-use valuations for land development planning using physiographic site information in combination with other resource data.

The mapping techniques developed by Hills and his colleagues were very comprehensive and provided a major influence on the later development of both the Canada Land Inventory (Anonymous 1965; McCormack 1966, 1970) and the Ontario Land Inventory (Anonymous 1977), two major land capability evaluation programs that mapped extensive areas of the province at scales of 1:250,000 and smaller. Mapping and site classification approaches developed by Hills (1952, 1960, 1961) were also in part adapted to an extensive set of land classification surveys conducted mainly in northern Canada during the late 1960s and 1970s. Referred to as Biophysical Land Classification (Lacate 1969) or Ecological Land Classification (Wiken *et al.* 1981; Wickware and Rubec 1989), these programs were undertaken mainly to provide broad-scale multiple-resource inventories of northern terrain or broad-area treatments at a regional or provincial level.

Forest stand classification based on height-age relationships has been used for many years in Ontario for yield forecasting. The "Site Class", based on tree height and age (Plonski 1974), is estimated for every mapped forest stand in the provincial Forest Resource Inventory (FRI) (Osborn 1989). Site Class conveys valuable information for forest harvest planning, but the usefulness of this type of height-age classification, by itself, is limited for many other purposes (Burger 1976; Jones 1984). Currently, there are limited numbers of other resource survey databases in Ontario and each provides only part of the information really needed for silviculture or integrated resource management purposes (Table 1). Pierpoint and Uhlig (1985) provide a complete listing and summary of the available resource surveys for the province.

Recently, Prime Site classification has been tested in Ontario as a tool for assisting regional forest management. Prime Site classification attempts to integrate, by means of Geographic Information System (GIS) modeling approaches, more stable physical site parameters and current wood volumes with other important but changeable technological and socio-economic criteria such as location in relation to transportation corridors and market conditions. Background work to delineate the physical map units as a basis for this work has been initiated in various parts of northern Ontario (Greenwood 1987; Towill and Sims 1989; Burger and Pierpoint 1990). Forest planning decision support systems and timber supply models are currently being developed for pilot

Table 1. An estimate of the abilities of existing resource inventories in Ontario to meet some of the various informational requirements for integrated resource management (O=not useful, X=useful, XX=very useful).

	FRI[1]	FEC	Agricultural Soil Survey	OLI	SO/NOEGTS
Planr ing horizon					
Short-med. term (1-5 yr)	XX	XX	X	X	X
Long-term (5-20 yr)	XX	XX	XX	XX	XX
Normal scale/resolution	1:20 000	Ground-based	1:10 000 (variable)	1:250 000	1:100 000
Extent of coverage in Ontario	Widespread	Local surveys only	Mostly scattered over small areas	Widespread	Widespread
Species composition	XX	XX	O	O	O
Working group	XX	X	O	O	O
Stand density and spacing	XX	X	O	O	O
Present productivty	XX	XX	O	O	O
Potential site quality	O	XX	XX	X	X
Product type/product amount	X	X	O	O	O
Non-commercial forest types	X	X	X	O	O
Depth of mineral soil	O	XX	XX	X	X
Depth and type of organic matter	O	X	XX	X	X
Soil moisture regime	O	XX	XX	XX	X
Soil texture	O	XX	XX	XX	XX
Macro/microtopography	O	X	XX	X	X
Surfical geology/landforms	O	X	X	X	XX
Wildlife browse prediction	O	XX	X	O	O
Fisheries concerns	X	X	XX	X	XX
Competition prediction	O	XX	X	O	O
Windfirmness	X	X	X	O	O

[1]FRI = provincial Forest Resource Inventory (Osborn 1989), FEC = Forest Ecosystem Classification, OLI = Ontario Land Inventory (Anonymous 1977), SO/NOEGTS = Southern Ontario-Northern Ontario Engineering and Terrain Survey maps (e.g. Mollard and Mollard 1981).

mapping areas, for example as part of the Plonski Forest study (Bulger and Hunt 1991), and will provide the computer-assisted capability to test Prime Site concepts rigorously.

Stand-Level Studies

Prior to 1970, detailed ecological data sets were not gathered for the purpose of comprehensive analysis, and most field data collected at the stand level was acquired either as demonstration material or to assist photo-interpretation exercises for land inventories such as the Ontario Land Inventory (Anonymous 1977). In addition, statistical methods and computer capabilities for handling, processing and evaluating such large datasets were not yet sufficiently developed and available.

Pre-1970 stand-level investigations by Hills and his colleagues contributed significantly to basic concepts of forest site description (Burger 1972b, 1977; Pierpoint 1981). Their investigations provided some important initial documentation and description of stand-level conditions (Hills 1950, 1952, 1954; Pierpoint 1962, 1981). In a land-use study of the Glackmeyer Development area in the Northern Clay Belt, Hills and his colleagues (1960) provided a remarkably thorough treatment of forest succession patterns as they relate to the commonly occurring physiographic sites in the area. Each vegetation description included summaries of dominant soil moisture regime, depth to bedrock, landform and humus type, as well as comments on possible succession patterns after disturbance (Hills *et al.* 1960). Applying Hills' classification approach to a broad study area in northwestern (NW) Ontario, Zoltai (1965, 1974) identified 24 landtypes defined primarily on the basis of geological material, soil texture, soil depth and stoniness. Zoltai (1965) also described the common overstory associations which occur across each of these landtypes. Studies such as these have prompted scientists and foresters to focus on important site-related criteria controlling forest growth and development at the stand level.

There are a number of other important early contributors to stand-level site classification in Ontario. Working in the Northern Clay Belt of northeastern Ontario, MacLean and Bedell (1955) conducted a growth and yield survey of forest stands emphasizing the influence of topographic location and soil wetness on forest productivity. They recognized several groupings of upland and lowland forest types mainly on the basis of soil characteristics such as "wet swamp", "very wet swamp" and "shallow peatlands". Earlier, for a broad area centered around Lake Nipigon, 13 merchantable and three unmerchantable site types were also recognized on the basis of similar topographic and soil wetness criteria (Bedell and MacLean 1952). Stratifying these units mainly on the basis of broad soil texture classes, Bedell and MacLean correlated these site types with selected mensurational measurements. For the Abitibi Woodlands Laboratory near Raith, Ontario, Losee (1955) developed a preliminary site classification system that identified nine different understory vegetation communities. They were grouped into categories he thought could be correlated with low, intermediate and high soil fertility levels. Ahti and Hepburn (1967) undertook an aerial reconnaissance and ground survey over a broad area of the Precambrian Shield north of Lake Superior in an attempt to assess the quality of woodland caribou habitat. They presented a general vegetational community classification for lichen-dominated upland stands as well as a wetland classification based on general physiognomy and dominant vegetation. For portions of the Hudson Bay Lowland of northern Ontario, Hustich (1957) and Sjors (1961, 1963) provided comprehensive descriptions of upland and lowland vegetational communities in relation to site factors such as soil texture and groundwater chemistry. Other

researchers such as Maycock (1960, 1963) examined the vegetational relationships of upland forest stands in southern and central Ontario as well.

In the period after 1970, there was a considerable amount of work conducted on stand-level forest ecology; as well, new information on function and dynamics was obtained. In general, studies were more quantitative, allowing ecological relationships to be examined more critically (Carleton and Maycock 1978; Carleton 1980, 1985; Kenkel 1986; Carmean 1987). Vegetational studies on Ontario wetlands and peatlands were conducted as a basis for developing site classifications (Jeglum *et al.* 1974; Jeglum and Boissonneau 1977; Sims *et al.* 1982; Vitt and Bayley 1984; Kenkel 1987; Cowell *et al.* 1991). Jeglum (1985) summarizes important developments in wetland site classification in Ontario.

Many of these landscape-level and stand-level research studies and resource surveys provided excellent baseline information on the forest ecosystems of Ontario. Hills and his colleagues, and ensuing studies by others, also provided a great deal of philosophical and methodological background on forest site and forest land classification. In the late 1970s, against this backdrop, and amidst evolving forest site classification activities in other parts of North America, the first of what were to be a series of Forest Ecosystem Classification (FEC) programs was begun in the Northern Clay Belt (Jones *et al.* 1983; Jones 1984).

Figure 3. Map of Ontario showing the extent of geographic coverage by Forest Ecosystem Classification systems; *completed* (diagonal hatching) and *in progress* (dot pattern).

Development of Forest Ecosystem Classifications in Ontario

General

FEC systems have been completed or are currently in development for a broad geographic zone across north-central Ontario (Figure 3, Table 2), covering most of Rowe's (1972) Boreal and Great Lakes-St. Lawrence Forest Regions. Small area studies using an FEC approach have also been completed (Wickware and Cowell 1985).

The FEC systems in Ontario are designed to permit the accurate, consistent and practical description of forest ecosystems so that existing and new management knowledge can be organized, communicated and used more effectively. FEC units are flexible and at least partly hierarchical; some demonstration studies have been undertaken to show that units can be mapped at various scales as well as integrated with other data bases to augment the background information for an area for forest planning and decision making.

The most recent FEC programs (Jones *et al.* 1983; Merchant *et al.* 1989; Sims *et al.* 1989) have been enthusiastically received. Concise and accessible formats coupled with a major effort in training and transfer has meant that FEC terminology and ecosystem thinking is becoming part of the resource management culture of Ontario. The user group now includes the public, policy makers, researchers and planners for a variety of resource fields. Applications range from wildlife habitat evaluations, environmental assessment and forest growth and yield interpretations, to the use of FEC units as a basis for keeping landbase records and monitoring long-term effects.

Rationale and Approach

A primary consideration in the development of FECs is that they are purposive. It should be noted that the FEC systems in Ontario, without exception, were first constructed for a specific and predefined range of uses. These included the organization of silvicultural practice and knowledge and the orientation of practical forest management information within a framework that recognized on-the-ground characteristics of understory vegetation, soils, landform, general climatic regime and regional physiography (Table 2).

FEC systems are primarily stand-level planning tools. They are designed to help foresters and other resource users obtain specific descriptive information about local forest stand, vegetation, soil and site conditions, which in turn can help develop management strategies and alternatives. Used and applied in a somewhat different way, the regional FEC systems are also effective mechanisms for tying in other scales of forestry data and other levels of planning information.

In the existing Ontario FEC systems, Vegetation and Soil Types are basic units. Both are determined through a "key-out system" that can be applied in the field quickly. For certain broader-level management purposes, FEC units come together as Operational Groups (OGs) (Jones *et al.* 1983), Treatment Units (TUs) (Sims *et al.* 1989) or Site Types (STs) (Merchant *et al.* 1989).

FEC Programs

FEC data collection standards were developed in 1978 during the initial phases of the Clay Belt FEC program (Jeglum *et al.* 1983; Jones *et al.* 1983). Field work was conducted during successive summers. Computerized FEC databases were constructed. For each area investigated to date they include detailed soil, site and vegetation information from mature or harvestable forest stands. Currently, a centralized computer inventory contains data on approxi-

Table 2. An overview of completed and ongoing Forest Ecosystem Classification programs in Ontario (NER FEC = Northeast Region FEC, CR FEC = Central Region FEC, IRM = integrated resource management).

	Clay Belt (Jones *et al.* 1983)	NER FEC	NW Ontario (Sims *et al.* 1989)	Algonquin[1] (Merchant *et al.* 1989)	CR FEC
Parameters					
Completion date	1983	ongoing	1989	1989	ongoing
Extent of coverage	50 400 km^2	—	184,000 km^2	35,300 km	—
Emphases	silviculture	IRM	silviculture & IRM	productivity of Pw and Pr	IRM
Main FEC units	14 Soil and 23 Vegetation Types, Operational Groups	ongoing	22 Soil and 38 Vegetation Types, Treatment Units	10 Soil and 14 Vegetation Types, Site Types	ongoing
Number of FEC plots	250 plots	—	2170 plots	201 plots	—
Management interpretations for					
Harvesting/silviculture	yes	—	yes	yes	—
Stand/site productivity	yes	—	yes	yes	—
Wildlife & other resources	yes	—	yes	no	—
Pilot mapping studies	yes	—	yes	no	—

[1]The Algonquin FEC deals only with white pine (Pw)- and red pine (Pr)-dominated forest ecosystems; when completed, the CR FEC will describe other forest ecosystems.

mately 2,800 FEC plots throughout the province (McLean and Uhlig 1990).

Information on the use of the various FEC systems has been transferred to operational staff through the publication of reports, maps and field guides, together with an intensive, ongoing training program. Three- and four-day FEC courses have been conducted throughout Ontario over the past 8 years (e.g., see Sims 1990) in basic forest soils description, identification of forest vegetation, field applications and interpretations, and mapping of soil-landform relationships.

Application of FEC Systems

The FEC systems in Ontario provide a set of regional frameworks for site description. Vegetation and Soil Types determined from field keys are described in sets of accompanying fact sheets. Once a forest site has been classified, a variety of short- and medium-term forest management interpretations may be considered and applied. The systems are applicable at a variety of levels and intensities, and are valuable to different users and for applications that involve various forest management objectives. For example, as a stand-level tool, FEC systems have been applied successfully as part of an operational cruise or pre-harvest assessment procedure (Stanclik 1986; Towill *et al.* 1988; Campbell 1990).

Through a keying process, forest stands can be allocated to specific FEC Vegetation and Soil Types in the field. Once allocated by means of these keys, stands are compared to corresponding factsheet descriptions of Vegetation and Soil Types in the FEC field guides (Jones *et al.* 1983; Sims *et al.* 1989; Merchant *et al.* 1989). While the allocation process varies somewhat among the completed systems, in general it follows two steps:

- The forest stand is allocated to a Vegetation Type. The user applies a field key that incorporates overstory trees and diagnostic understory plants.
- The soil profile underlying the stand is allocated to a Soil Type. The user applies a field key which asks for a few critical soil parameters (e.g., soil depth, parent material texture, soil moisture regime) determined through an examination of soil material from either a soil pit or an auger hole.

Computer-assisted ordinations (Hill 1979; Gauch 1982) provided a means to summarize FEC vegetational cover information succinctly. Ordinations have been used widely to study vegetational relationships within boreal forest ecosystems (Carleton 1980, 1985; Zelazny *et al.* 1989; Cowell *et al.* 1991). Ontario FEC ordinations (e.g. see Figure 4a,b) were based on percentage cover and relative abundance information for a large number of vegetation species recorded in 10 × 10 m sample plots. The FEC ordinations portray Vegetation Types within soil moisture-nutrient two-dimensional graphs, much in the way that the Alberta and British Columbia biogeoclimatic systems organize ecosystem units within edatopic grids (Corns and Annas 1986; Green 1990). Information about other soil, site or vegetation parameters is readily overlaid on FEC ordinations as a means of highlighting relationships (Wearn *et al.* 1982; Jeglum *et al.* 1983; Jones 1984; Racey *et al.* 1989a; Baldwin and Sims 1989).

Operational Groups and Treatment Units

Operational Groups (OGs), Treatment Units (TUs) and Site Types (STs) are management-oriented aggregations of FEC Soil and Vegetation Types that possess similar species composition, productivity, and macroclimatic or ecological properties (Jones *et al.* 1983; Racey *et al.* 1989a; Merchant *et al.* 1989). OGs, TUs and STs are easily determined in the field and usually represent broad landscape units that should respond similarly to a given regime of silvicultural treatments. They provide aggregations of FEC units that can, in some situations, be used to develop interpretations for forest management (Figure 4a,b, 5). Similar OG or TU units are used to help describe forest management options in New Brunswick (Zelazny *et al.* 1989), Alberta (Corns and Annas 1986) and British Columbia (Klinka *et al.* 1984).

OGs, TUs and STs are less precise in describing soil-site and vegetational characteristics than are FEC Vegetation and Soil Types, but it is often possible to re-divide them into

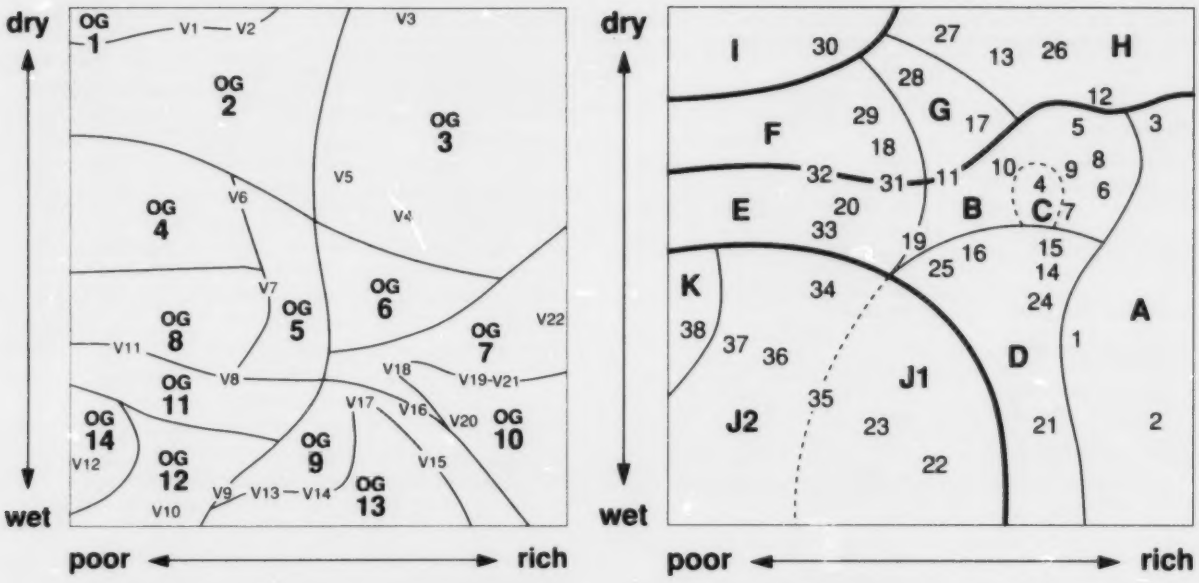

Figure 4. (left) Clay Belt FEC vegetational ordination of Vegetation Types overlain with Operational Groups and showing broad gradients of nutrients (x-axis) and moisture (y-axis) (Jones *et al.* 1983), (right) NW Ontario FEC vegetational ordination showing Vegetation Types overlaid by Treatment Units and with similar moisture/nutrient gradients (Sims *et al.* 1989).

component Vegetation and Soil Types. OGs, TUs and STs can also be delineated into Phases in which secondary features can influence certain specific responses to management activities. Phases serve to focus management options, and can be defined, for example, on the basis of soil moisture regime groupings (cf. Racey *et al.* 1989a) and shrub-richness or soil-depth classes.

FEC as a Framework for Forest Management Interpretations

A wide variety of forest management interpretations have been integrated with site classification systems (e.g., Corns and Annas 1986; Kotar *et al.* 1988; Zelazny *et al.* 1989; Green 1989). Similar approaches have been used to develop forest management interpretations for Ontario FEC systems (Tables 2 and 3; see also Jones *et al.* 1983; Jones 1984; Racey *et al.* 1989a; Merchant *et al.* 1989; Stocks *et al.* 1990). Five different examples of FEC-based forest management interpretations are outlined in the following sections.

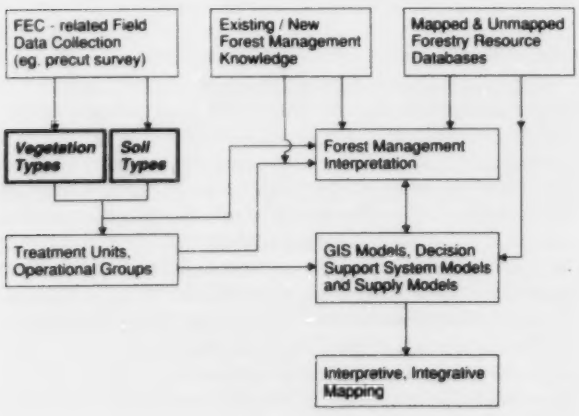
FEC - related Field Data Collection (eg. precut survey)
Existing / New Forest Management Knowledge
Mapped & Unmapped Forestry Resource Databases
Vegetation Types
Soil Types
Forest Management Interpretation
Treatment Units, Operational Groups
GIS Models, Decision Support System Models and Supply Models
Interpretive, Integrative Mapping

Figure 5. Organization of FEC Soil and Vegetation Types so that, with the input of management information and knowledge, management interpretations and other products may be developed iteratively.

Preparing Prescribed Burn Guidelines

Prescribed burning is used by foresters to achieve specific management objectives such as slash reduction, wildfire hazard reduction, disease control, site preparation for regeneration, wildlife habitat improvement or any combination of these or other objectives. Planning for prescribed burns should consider all relevant site factors, including expected fuel loading, substrate, soil moisture and physiography.

FEC units can be used to stratify sites for the calculation of the required fire intensities, and the determination of the vegetation and soil conditions to be considered in the planning of prescribed burns. Wearn *et al.* (1982) provide a Clay Belt FEC interpretation for prescribed burns in which the management objective is to prepare the site for hand planting. An ordination overlay (Figure 6) is used to assist the manager in determining the required intensity of burns. Accompanying sets of pre- and post-burn colour site photos (Wearn *et al.* 1982) are catalogued according to FEC Vegetation Type, and provide an additional aid for the forester, indicating results that might be expected on different sites given different sets of fire weather indices.

A similar ordination overlay is provided for the NW Ontario FEC by Racey *et al.* (1989a). Fuel loadings and wildfire potentials of Vegetation Types have also been estimated (Stocks *et al.* 1990).

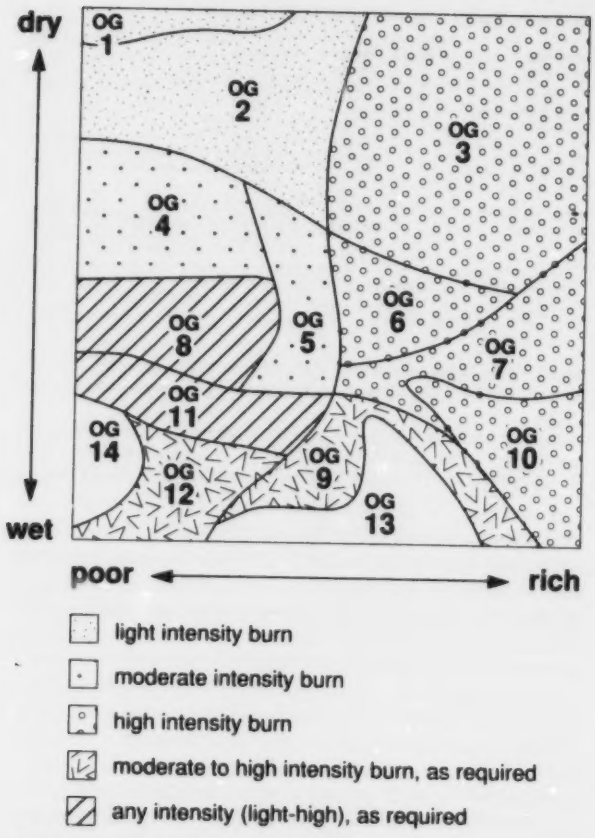

Figure 6. Clay Belt FEC ordination (as in Figure 4a) showing recommended intensities for prescribed burns as a site preparation technique prior to hand planting (after Wearn *et al.* 1982).

Organizing Ecological Information on Competitive Species

When combined with keen field observational skills and experience, summarized autecological information on competitive species, presented within a site classification framework, can help foresters improve forest vegetation management practices significantly (Wagner and Zasada 1991). There are 23 common understory species identified as serious competitors with crop trees in NW Ontario. For each species, Bell (1991) reviews a variety of descriptive information such as associated NW Ontario FEC Vegetation and Soil Types, life cycles, reproduction, and soil-site characteristics conducive to growth (Figure 7). There are also summary comments for each species in terms of the forestry practices that stimulate or reduce growth or establishment, and the utilization of the species by wildlife. Information is summarized on current methods used for control or management of the species.

Summary information on the ecological range of other understory vegetation species is provided in a plant identification guide for the NW Ontario FEC (Baldwin and Sims 1989). This handbook provides identification aids and habitat information on 157 forest plant species, including common trees, shrubs, herbs, graminoids, ferns, mosses and lichens. The publication includes individual NW Ontario FEC ordination diagrams for each species and shows associated

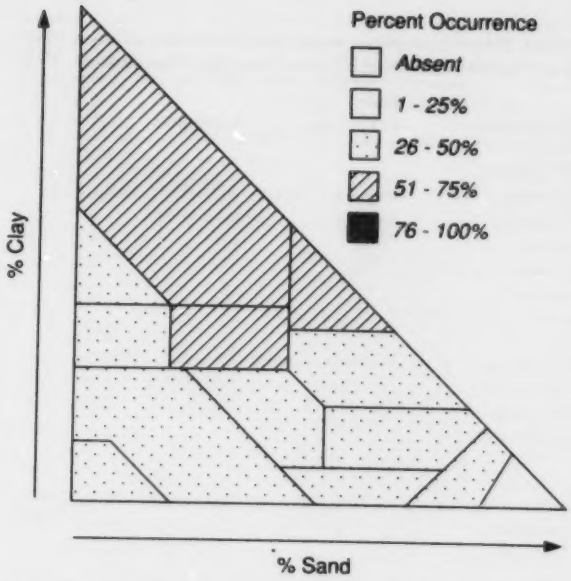

Figure 7. Frequency of occurrence of beaked hazel (*Corylus cornuta* Marsh.) according to soil texture classes, shown as an overlay on a soil texture triangle; based on field information summarized from the NW Ontario FEC program (Bell 1991).

Vegetation Types and species distributions across interpreted moisture-nutrient gradients.

Estimating Soil-Associated Constraints on Forestry Operations

A variety of operational constraints can be related to soil texture, soil moisture, the presence of significant quantities of coarse fragments, and other soil parameters that may be associated with or derived from FEC Soil Types. For example, soils generally become less susceptible to erosion as clay or sand content increases, and more susceptible as silt content increases. A soil's surface condition (e.g., residual vegetation, surface texture, etc.) and the frequency, intensity and duration of rainfall can also influence a local area's susceptibility to soil erosion. In addition, susceptibility to erosion is often greatest where slopes exceed 10%; long, steep, uniform slopes are particularly vulnerable. Erosion generally decreases with increasing amounts of residual vegetation and slash left on a site, and increases with an increasing degree of disturbance to surface organic layers.

Such considerations are incorporated into a simple NW Ontario FEC interpretation that deals with the soil erosion hazard (Figure 8). The chart, intended to be used in the field as a "look-up table", provides low, moderate and high erosion-hazard ratings that are based on NW Ontario FEC Soil Types (Racey *et al.* 1989a). Its intent is to alert the forest planner to potential problems; moderate or high ratings should prompt consideration of measures to reduce potential soil erosion.

The Kapuskasing District of the Ontario Ministry of Natural Resources (OMNR) has produced a photo guide to harvesting and regeneration options using the Clay Belt FEC as a framework for site descriptions (Anonymous 1987). The photo guide provides pre- and post-harvest sets of color

Table 3. Selected examples of forest management interpretations based on the Northwestern Ontario Forest Ecosystem Classification.

Interpretation	Main FEC Units	References
Silviculture		
Determining the competition potential for selected understory species	Vegetation Types/ Soil Types	Bell (1991), Baldwin and Sims (1989)
Defining the autecological preferences of common tree species	Vegetation Types/ Soil Types	Sims et al. (1990), Bell (1991)
Predicting the productivity of jack pine stands	Soil Types	Leblanc and Towill (1989), Racey *et al.* (1989a)
Predicting the potential for advance growth following logging	Vegetation Types	Wickware *et al.* (1990), Walsh and Wickware (1991)
Wildlife habitat		
Predicting moose habitat preferences	Vegetation Types	Racey *et al.* (1989b), Jackson *et al.* (1991)
Predicting habitat selection by forest-nesting bird species	Vegetation Types	Racey *et al.* (1989a)
Predicting caribou habitat preferences	Vegetation Types	Morash and Racey (1990)
Landscape features		
Correlating surficial landform features with FEC Units	Soil Types	Sims *et al.* (1991)
Interpreting black and white air-photos for FEC units	Vegetation Types/ Soil Types	Wickware (1989)
Constructing common toposequence patterns for landform complexes	Vegetation Types/ Soil Types	Baldwin *et al.* (1990)

photos with information on soil characteristics, vegetation competition after harvesting and the extent of soil degradation that can occur if narrow-wheeled harvesting equipment is used on certain organic Soil Types. A videocassette recording also accompanies the report and photo sets (Anonymous 1987).

Soil conditions influencing erosion hazard

*NWO FEC Soil Types**	*Slope (%)*	*Erosion Hazard*	*Comments*
S12F, S12S, S59, S11		Low	
S2, S4, S8, S10, S11, SS1, SS2, SS3, SS4, SS7, SS8	≤10 >10	Low High	Fluvial materials or extensive surface disturbance will increase hazard
S9, S3, S5, S6, S7, S8, SS5 SS6	≤10 >10	Low Moderate	Morainal soil materials, variable particle sizes, coarse fragment content >35%, or thick surface organic layers may reduce the erosion hazard

* assumes a relatively close correlation between surface texture and C horizon texture

Figure 8. Prediction of potential erosion hazard (low, moderate, high) on the basis of Soil Types from the NW Ontario FEC system (Racey *et al.* 1989a).

Predicting the Productivity of White and Red Pine

A number of investigations have been undertaken to examine site productivity relationships of FEC units. The Algonquin Region FEC (Merchant *et al.* 1989) incorporates a methodology for estimation of white and red pine productivity. To apply the system, a given stand must meet several criteria: it must be natural pine-conifer only, have an estimated minimum of 60% white pine or red pine by basal area, be relatively fully stocked, have been undisturbed for the past 25 years, and be mature, usually at least 75 years of age. As in the other FEC systems (although sometimes the Soil Type in a given location may be inferred from the Vegetation Type), it is more accurate to determine the Soil Type directly either by digging a soil pit or augering a hole.

The Algonquin FEC system uses a combination of Vegetation Types and commonly associated Soil Types to characterize Site Types (STs), which are in turn related to classes of site index at 75 years and mean annual increment for each of the two pine species (Merchant *et al.* 1989). STs are defined as classes of similar forest ecosystems on the basis of soil and vegetation features that can affect forest productivity and management. Additional productivity information is summarized by STs in Taylor and Jones (1989). The Site Type Information Table (Figure 9) associated with each Vegetation Type fact sheet also provides common soil-site conditions, a "quality warning" which gives some indication of potentially decreased stem quality due to rot, and a rating of potential competition (low, moderate, high, very high) after harvest (Merchant *et al.* 1989). Other studies that have specifically examined productivity relationships with FEC Vegetation and Soil Types include Munson and Timmer (1989a,b), LeBlanc and Towill (1989), Whynot and Penner (1990), Buse and LeBlanc (1990) and Li (1991).

Describing the Habitat of White-tailed Deer

White-tailed deer are restricted to the southwestern corner of NW Ontario. An FEC interpretation (Figure 10) was prepared to highlight Vegetation Types that are usually capable of producing preferred browse (food) species and winter shelter for the deer in areas to be managed for that purpose (Racey *et al.* 1989a,b).

The limiting factor for white-tailed deer in NW Ontario is usually considered to be winter severity. Tree cover that

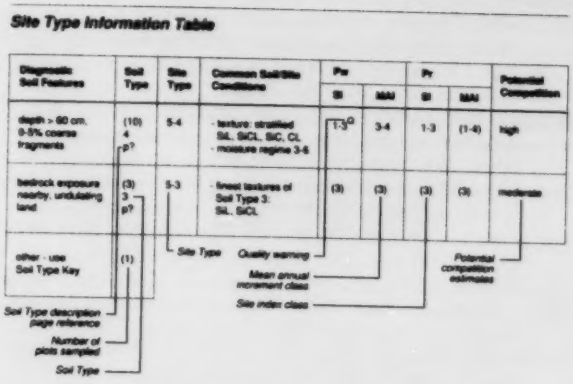

Figure 9. Section of a fact sheet from the Algonquin FEC manual (Merchant *et al.* 1989) highlighting the various parts of the pine productivity "look-up table".

offers some protection from severe cold and deep winter snow is essential. White-tailed deer are generalist herbivores with critical energy requirements, particularly during winter (Racey *et al.* 1989b; however, since most of their energy intake occurs during the snow-free period, good-quality summer forage, especially grasses, deciduous leaves and a variety of herbaceous species, is essential. Other factors include the patterns and juxtapositions of habitat across the landscape, habitat diversity, topography and the general age-class distribution of forest stands in an area.

Similar ordination-based interpretations have been constructed to describe caribou (Morash and Racey 1990) and moose habitats (Racey *et al.* 1989b; Jackson *et al.* 1991) in NW Ontario.

Future Challenge for Forest Site Classification in Ontario

Recently forest management in Canada has entered a phase of ecologically based forestry, with the two-pronged goal of sustaining yield and environmental quality (Kimmins 1991). There is a need, therefore, for a determined shift in our current approach to integrating forest management concerns into operational practice. The various forest users and stakeholders must focus on the achievement of mutual goals, instead of the current approach, under which they attempt to set limits and constraints on each others' jurisdictions and interests.

Although considerable progress has been made over the past 40 years, there are still many new challenges emerging for site classification research in Ontario. Linkages must be strengthened among existing FEC systems and those now under development, so that underlying principles, methodologies, presentation approachs and outputs are standardized, wherever practice. FEC systems are needed for areas of the province not already adequately covered by integrated ecologically-based site classification systems. More research and development is needed to integrate FEC units with timber supply models. wildlife supply models, and, in particular, a variety of specific-purpose, spatially based models, with the use of GIS, remote sensing and other new technologies and tools.

Additional forest management interpretations related to existing FEC systems must be developed so that foresters

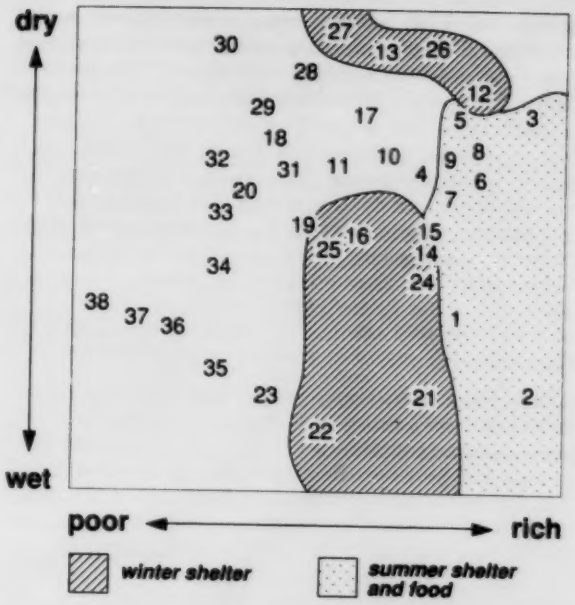

Figure 10. NW Ontario FEC vegetation ordination (as in Figure 4b), overlain with winter and summer shelter and food requirements for white-tailed deer (Racey *et al.* 1989a).

can have better access to up-to-date information classified by site feature. Successful forest management practices must be documented and reported, both by area and by site: it is important for FEC interpretations to be tied to management successes which can be related to specific site features. In this way, FEC will continue to be an important tool for strengthening communication among a variety of policy makers, resource managers and planners, as well as the general public. There are other potential applications for FEC that have not previously been considered. For example, Bailey (1991) outlines a procedure for establishing ecological networks for global-change monitoring which involves the systematic selection of candidate sites on the basis of information acquired from regional site classifications.

As important environmental issues emerge in Ontario, a myriad of new ecosystem-related information needs are being identified. Throughout Ontario, regionally-based ecological data bases need to be collected, perhaps as an adjunct to the provincial FRI program, and organized so that they can be readily accessed for integrated ecosystem-oriented planning. Post-disturbance vegetational classifications should be developed for a range of boreal sites, and perhaps correlated to FEC units. There should be new emphases on understanding processes and functions within boreal forest ecosystems at the landscape level, as well as new research on biodiversity, ecological properties of old-growth forests, and pathways for vegetational succession and long-term ecological change.

Corporate planning and monitoring in a jurisdiction as large as Ontario will need co-ordinated ecological information, and in some instances a common provincial template, on which to develop dynamic inventories and resource management models. The OMNR is currently developing plans for a provincial-scale program of comprehensive, mapping-oriented

ecological land classification (ELC) which incorporates FEC. In this new ELC program, current FEC databases and products will be augmented in a systematic fashion to capture a wider range of ecosystems, with minimal disruption to current FEC users. Efforts will be made to address the broader ecological spectrum by capturing non-forested ecosystems, such as wetlands, within the ELC format. ELC products will be designed to serve a broad range of users and interpretations, and will require the development of new spatial models for area resource management planning. The development of GIS technologies and the linkage to component relational databases and existing forest inventories will undoubtedly comprise a major part of this future work.

Conclusions

Hills' Site Regions are still widely used as a regional-level stratification for a variety of silvicultural purposes, including provincial seed collection zones (Pierpoint 1986). The FEC systems that have been developed subsequently owe much to the initial studies of Hills and his colleagues. Currently available FEC systems in Ontario have found increasing use over the past few years by government and industrial forestry staff as an aid in making day-to-day decisions. The available site classification systems have also been useful for the communication of forest management successes and failures, and for the effective implementation and transfer of new technology and information.

The ecological characteristics of Ontario forest lands must continue to be assessed, and component sites that differ enough to warrant different treatments must be identified. Operational guidelines for foresters can and should be prepared within the framework provided by FEC systems. In a list of recent recommendations, the Forest Research Advisory Council of Canada highlighted the need for a concerted effort to connect research activities with site classification systems (Anonymous 1991). Such an effort may well serve to broaden the use of research results in ways that maximize their application and avoid their use in inappropriate situations. This important activity will continue to be emphasized during the 1990s within the framework of Ontario's FEC and ELC initiatives.

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User information needs for forest management site classification in Manitoba

by Russell E. Wells[1]

Abstract

Forest inventory in Manitoba reveals that considerable forest harvest expansion is possible because of present underutilization. Although underutilization does occur in some forest sections, Manitoba's 20-year forest management plan predicts shortages of softwood in currently utilized sections before the end of this decade. Better forest management is recognized as one way to overcome these expected shortages. Development of an effective forest management site classification system is seen as a necessary basis for this implementation. As a prerequisite to the development of such a system, current and future site classification information needs of professional management foresters in Manitoba were surveyed by means of a questionnaire and personal interviews. They were asked to identify the kinds of site classification information needed for different forest management programs and decisions, and to further qualify these in terms of location, scale and temporal suitability. Results of this survey indicate that a system involving both mapping and site-specific approaches is needed.

Keywords: forest site classification, Manitoba, forest management, user needs, site mapping

Résumé

Au Manitoba, l'inventaire forestier révèle qu'il serait possible d'accroître considérablement la récolte, en raison de la sous-utilisation actuelle des ressources forestières. Bien que ce phénomène s'observe dans certains secteurs forestiers, le plan d'aménagement de vingt ans mis sur pied au Manitoba prévoit toutefois des pénuries de bois de résineux dans les secteurs actuellement exploités, et ce avant la fin de cette décennie. On reconnaît que la mise en œuvre d'activités d'aménagement forestier de plus haut niveau serait un moyen de surmonter les pénuries prévues. On considère que l'élaboration d'un système efficace de classification des sites d'aménagement forestier est essentielle à cette démarche. Avant d'établir un tel système, on a consulté les aménagistes forestiers professionnels du Manitoba par le biais d'un questionnaire et d'entrevues afin de connaître leurs besoins actuels et futurs en matière de classification des sites forestiers. Les aménagistes devaient identifier les types de données sur la classification des sites nécessaires à divers programmes d'aménagement forestier et à des prises de décisions, et préciser davantage leurs besoins en matière de localisation, d'échelle cartographique et de calendrier d'exécution. Les résultats de cette enquête démontrent la nécessité d'un système combinant la cartographie et les méthodes particulières à un site.

Mots clés: besoins des utilisateurs, cartographie des sites, classification des sites forestiers, aménagement forestier, Manitoba

Introduction

Size and Extent of Forests

For broad forest classification purposes, Manitoba is subdivided into two major areas — the Tundra Transition Zone and the Forest Zone (Manitoba Natural Resources 1987). The Tundra Transition Zone (Forest and barren, Figure 1) occupies the northern 35% of the province and presents no or minimal possibilities for forestry use. The Forest Zone covers the southern 65% and includes all of the productive forest land as well as the province's agricultural lands. Thirty-eight percent, or 14.9 million hectares, of the Forest Zone is considered as commercially productive forest. This productive forest area which is estimated to include 746 million m^3 of merchantable wood volume, 463 and 283 million m^3 of softwood and hardwood, respectively, ranks Manitoba fifth among Canadian provinces and territories in terms of forest area and timber volume. Although Manitoba has more than sufficient wood to meet its current needs, the most important issue facing the forestry sector may be the future wood supply (Forestry Canada 1990). Manitoba's 20-year forest management plan indicates that by the 1990s, the softwood supply in the currently utilized forest sections will fall short of expected demands (Manitoba Natural Resources 1987).

Level of Forest Management Activity

For forest management purposes, the Forest Zone is subdivided into 10 Forest Sections, each of which is further subdivided into Forest Management Units (Figure 1). Most of the productive forest land, approximately 90%, is owned by the province. Of the remainder, about 7% is privately owned and the rest is located on Federal Crown, municipal, local government district and Indian Reserve land (Manitoba Natural Resources 1987).

Manitoba Natural Resources, Forestry Branch has traditionally had the primary responsibility for forest management. However, starting around 1981, the forest industry has begun gradually to assume a greater share of forest management responsibilities, especially for forest renewal after harvesting. The extent to which this transfer in responsibility has been achieved is due largely to new 20-year forest management licence agreements between Manitoba Natural Resources and the two major commercial operators, Abitibi-Price Inc. and Manfor Ltd. (Steele and Williamson 1989). These agreements are continually renewable for 20-year periods and are subject to review at the end of 5-year management periods.

In view of these agreements, Manitoba Natural Resources, Forestry Branch has adopted a 20-year operational strategy

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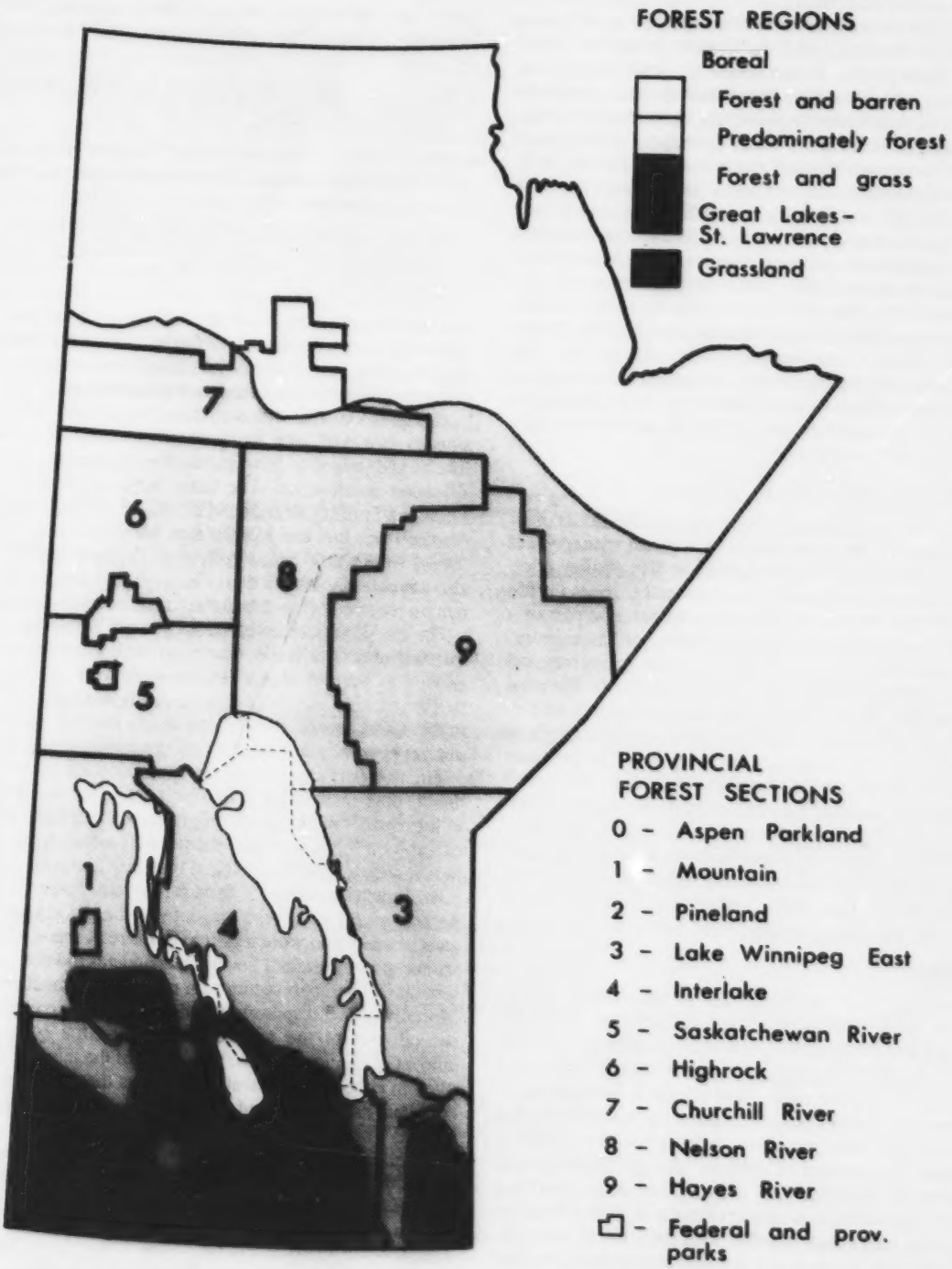

Figure 1. Forest Regions of Manitoba (adapted from Rowe 1972).

with increased management activity. Provincial timber dues are now adjusted annually and the dues structure is subject to complete revision every five years. Timber quotas are also revised on a five-year basis.

Much of this increase in forest management activity has been aided by funding under the Canada-Manitoba Forest Renewal Agreement. Forest nursery production, tree improvement and intensified stand management programs have received major impetus under the agreement. In addition, cost-shared funding under the agreement enabled purchase of a forest geographic information system (GIS) to help solve the increasing problem of forest data management and analysis. The GIS was installed in 1985 and is now operational in a number of Forest Sections. The forest inventory can now be updated on a continual basis in these areas. When all the data are entered, the system will also serve to integrate operationally the new forest inventory with its 4300 cover map sheets and 65 Forest Management Unit data bases (Manitoba Natural Resources 1987). Moreover, the implementation of the forest GIS means that the Manitoba Forest Service now has the capability to begin the full integration of forest site classification information for improved management and planning.

User Information Needs

The desirability of assessing user information needs prior to the design and implementation of a forest management site classification has been recognized widely (Bailey *et al.* 1978; Coulombe *et al.* 1981). More recently, Jones (1985) considered user need assessment to be an integral part of a technology transfer process which includes need assessment, problem analysis, program planning, training courses and the actual implementation of the site classification. The need assessment step, in his view, is part of a continuing and iterative interaction between classifiers and managers throughout the course of a site classification program. The program implemented in the Ontario Clay Belt (Jones et al. 1983) used a questionnaire and interviews to identify and rank interpretive needs of forest managers in the region. To date, however, most forest site classifications have not included a survey of user information needs, although some of this work has usually been done verbally with direct contact between the site classifiers and field foresters.

Methods

Determining user needs is not an easy task. Forest managers, because their objectives are different, generally tend to see and understand forest sites differently from site classifiers. Until fairly recently, user information needs were generally for extensive rather than intensive forest management purposes. Now, however, multi-user demands on a finite forest land base are forcing a greater interest in intensive forest management. Currently, the development and application of improved GIS shows promise in providing users with a powerful new management tool. Rapid developments in this technology together with the interest and questions clients have about its use in forest management are also responsible for increasing user awareness of the importance of defining user needs before such systems are implemented. These new concerns and new awareness now help to make the task somewhat less difficult. Classifiers and managers seem generally more ready to recognize that some in-depth, mutual understanding of each others' problems is essential to the successful implementation of forest management site classification programs.

A questionnaire and personal interviews were used to survey the information needs of forest managers in the Manitoba study. The questionnaire was designed to determine:

- the forest management programs which require site classification information;
- the management decisions which require site classification information and whether these requirements are statutory or optional; and
- the site classification information which is required for each program or decision in terms of location, scale and content.

Personal interviews with selected managers were used as a follow-up to clarify details of the questionnaire responses and to bring out further details of forest management problems in particular forest management units.

The questionnaire was distributed to individuals professionally involved with management and use of Manitoba forests and judged to have some requirements for site classification information. The main target groups were the Manitoba Forestry Branch and the major private companies, Abitibi-Price Inc. and Manfor Ltd. Interested research personnel from the Winnipeg office of Forestry Canada were also canvassed to obtain their views on the kind of site information required by the Manitoba forest research community.

The questionnaire involved a dynamic rather than static assessment of user needs. Questions were asked about future as well as current needs. Respondents were not restricted to listing their needs from only currently available site information, and several respondents did in fact list information not yet generally available in all the management regions.

The two-part structure of the questionnaire gave respondents some difficulties. The first part asked the managers to list relevant management programs which require site classification information. The second part asked the managers to complete a separate, detailed response about the management decisions involved with each program. Potential respondents were provided with one copy of the second part of the questionnaire and were required to make as many additional photocopies as needed. Several respondents did not complete separate second-part sections for each management program. Moreover, the responses of those who did complete the second part of the questionnaire showed a considerable amount of duplication. The high value of the information supplied in either case, however, suggests that the information could have been obtained with a less complex questionnaire design. The design used was a modification of one used to determine soil survey user needs in Alberta (MacMillan 1985). If time had permitted, user input would have been solicited on the questionnaire format from each of the target groups, and could possibly have helped produce a simpler design.

Thirty questionnaires were distributed to individuals in the three sectors mentioned above and eighteen completed forms were returned. The proportion of returns is actually higher than the numbers indicate because forms completed by individuals from the industrial sector reflect the opinions of

several persons from each forest company. Conclusions based on these results can therefore be regarded as representative of all sectors.

Results

Results for Part 1 of the questionnaire provided information about active forest management programs and associated management decisions. These results indicate that site classification information for forest renewal and reforestation programs are of most concern to the broadest range of users in Manitoba (Table 1). This is also reflected in the greatest variety and larger numbers of citations for associated management decisions requiring site classification information. Site information for stand improvement and forest inventory or productivity are next, in descending order of importance. After that, site information appears to be of roughly equal concern for harvesting and for timber management or utilization programs. Other programs listed include budworm management, dwarf mistletoe management, forest fire behaviour, and economics of intensive forest management. These programs have a low number of respondents, mainly from the forest protection and research groups, but are not inconsequential because they indicate the broad range of user requirements for site information.

As for Part 2 of the questionnaire, the types of classification information associated with individual management programs cannot be reported in detail because only three respondents completed separate Part 2 sections for each management program cited. As a consequence, all user responses on type and usefulness of site information were pooled to gain some general understanding of user preferences (Table 2). Overall, these grouped results show some clear preferences. Most of the kinds of site information listed received moderate to highly useful (3 to 5) ratings by a majority of users. Only a few types, including soil pore pattern, soil chemical and engineering properties, and wildlife and engineering use ratings were either not used or received low to moderate ratings (1 to 3) by a majority of users.

The results are more instructive, however, when summarized by respondent group in Table 3. This summary shows that, in many cases, the variation in user requirements within groups is equal to or greater than that between groups. Some of this variation can be attributed to lack of separation of information requirements for individual management

Table 1. Summary of management programs and decisions using site classification information

Management program	Number of respondents	Management decisions	Number of times cited	Respondent groups
Harvesting	2	Harvesting system and method	2	Regional Foresters (1)
		Road location	1	Industry Foresters (1)
		Harvesting plan	1	
Forest renewal	9	Method of site preparation	6	Regional Foresters (2)
		Species to be planted	5	Silvicultural Foresters (2)
		Tending treatments	5	Industry Foresters (3)
		Matching stock type to site	3	Research Foresters (2)
		Matching stock species to site	2	
		Evaluation of regeneration	2	
		Selection of most productive sites	1	
		Monitoring of forest renewal activities	1	
Stand improvement	4	Priorization of sites	3	Regional Foresters (2)
		Projected stand development	1	Silvicultural Foresters (1)
		Treatment required	1	Industry Foresters (1)
		Location of seed orchards	1	
		Selection of plus trees	1	
Forest inventory, productivity	3	Calculation of annual allowable cut	2	Inventory Foresters (2)
		Location of temporary sample plots	1	Industry Foresters (1)
		Location of permanent sample plots	1	
		Production of volume tables	1	
		Development of growth & yield models	1	
		Location of forest land	1	
Timber management, utilization	2	Allocation and licences	2	Timber Management Foresters(1)
		Long-term planning	1	Regional Foresters (1)
Jackpine budworm management	1	Insecticide application	1	Forest Protection
		Silvicultural treatments	1	
		Salvage operations	1	
Spruce budworm management	1	Insecticide application	1	Forest Protection
		Salvage operations	1	
Dwarf mistletoe management	1	Sanitation in juvenile stands	1	Forest Protection
		Postharvest sanitation	1	
		Premature harvest	1	
		Host tree removal	1	
Forest fire behaviour	1	Fuel type mapping	1	Research Foresters
Economics of intensive forest management	1	Correlation of site with silviculture treatments	1	Research Foresters

Table 2. Types of site information required by all respondents

Information type	Not used	Usefulness[1] Slight 1	2	3	4	High 5	Number of times cited
Climate							
Ecoregion	15	0	8	39	23	15	13
Vegetation							
Cover type	0	0	0	18	24	58	17
Physiognomic group	31	15	0	23	0	31	13
Association	7	0	0	36	21	36	14
Dead and down	0	0	0	0	0	100	1
Geomorphology							
Surficial material	6	11	6	6	43	28	18
Landform	6	0	0	25	38	31	16
Topography	6	6	6	29	35	18	17
Slope	6	0	6	41	29	18	17
Moisture regime	6	0	0	0	41	53	17
Depth to bedrock	6	0	12	24	34	24	17
Soil							
Great Group, Subgroup	12	6	12	0	41	29	17
Association	22	18	18	12	12	18	17
Profile description	18	0	34	18	18	12	17
Humus form	18	6	18	6	34	18	17
Texture	6	0	6	18	35	35	17
Pore pattern	40	18	6	18	6	12	17
Structure	18	18	0	18	28	18	17
Drainage	6	0	0	12	35	47	17
Chemical properties	34	24	6	18	6	12	17
Engineering properties	52	6	18	12	6	6	17
Ratings							
Erosion	18	18	18	18	28	0	17
Forestry use (CLI)	13	7	0	0	20	60	15
Wildlife use (CLI)	50	7	22	7	7	7	14
Recreational use	33	0	26	8	0	33	12
Engineering use	76	8	8	0	8	0	13

[1]Figures are percentages of total number of times cited.

programs, as mentioned before. For example, the one industrial forester who did list separate requirements for different programs rated soil engineering and related properties higher for harvesting than for forest renewal programs. This is not surprising because equipment used for harvesting is much heavier than that used for planting. However, distinctions such as this could not be discerned in responses of the two other respondents (from other user groups) who also returned more detailed forms. The main conclusion here is that there appears to be a sizeable range of opinion within respondent groups as to what types of site information are essential for particular programs.

Scale of Mapped Site Information

All respondents showed a marked preference for a map scale of 1:20 000 or larger. This result is not unexpected because many foresters involved in operational activities can use site information at 1:20 000 or larger for intensive forest management. However, this also has serious cost implications for any site classification mapping program. Mapping costs usually increase almost exponentially with linear increases in scale. As a result, trade-offs in the amount of detail desired versus costs are unavoidable. Maps at larger scales are desirable but the cost of producing them may be prohibitive.

Present Information Source

Responses show that the forest inventory cover maps are currently the predominant source of site information. This may be so because nothing else with comparable detail and coverage is so generally available.

Lack of coverage and insufficient detail were sited by some respondents for low use of soil survey information. Concern about insufficient detail and accuracy of content appear to be major reasons for the low use of Canada Land Inventory (CLI) maps. Responses also revealed that use of special in-house studies and surveys by both government and private sectors is rather common and may indicate a lack of communication between site classifier and field forester, rather than that existing site information is not adequate for current needs. This last finding should probably receive more follow-up investigation because it may have considerable bearing, not only on the technical design, but also on the kind and amount of technology transfer to be included as part of any proposed site classification system.

Information Format

Most respondent groups prefer maps. Overall, although there were some exceptions within user groups, a majority of respondents indicate that the most useful information comes both from site specific data and map displays of original and interpreted site-classification data. There also appears to be a corresponding willingness to consult text descriptions of original map units. However, a greater number of respondents indicate that mapped displays of some secondary derived information, namely CLI data, are of no or little use than those who report moderate to high usage. Extreme variation is characteristic of preferences within

Table 3. Types of site information required by each respondent group

Information type	Reg	Sil	Ind	Inv	Pro	Fir	Tim
Climate							
Ecoregion	H	O-H	O-M	O-H	M	H	O
Vegetation							
Cover type	H	H	H	H	H	H	H
Physiognomic group	H	O-H	O-H	O-H	L-M	M	N
Association	M-H	M-H	O-H	H	M-H	H	N
Dead and down	N	N	N	N	N	H	N
Geomorphology							
Surficial material	H	M-H	H	H	L-H	L	O
Landform	M-H	M-H	H	O-H	M-H	M	O
Topography	M	M-H	H	O-L	M-H	H	L
Slope	M	M-H	M-H	L-M	M-H	H	O
Moisture regime	H	H	H	H	H	H	O
Depth to bedrock	M	H	H	M-H	L-H	N	O
Soil							
Great Group, Subgroup	H	L-H	H	O	H	L	L
Association	M-H	O-H	M-H	O-H	L	L	O
Profile description	L-H	L-H	L-H	O	L-M	L	O
Humus form	L-H	L-H	L-H	O-H	O-M	H	O
Texture	M-H	H	H	M-H	M-H	L	O
Pore pattern	M	O-H	O-H	O	O-L	O	O
Structure	M-H	O-H	H	O-H	L-M	L	O
Drainage	H	H	M-H	H	M-H	H	O
Chemical properties	M	O-H	O-H	O	L	O	O
Engineering properties	L-M	O-H	O-H	O-L	O	O	O
Ratings							
Erosion	L-H	L-H	M-H	O-H	L-H	O	O
Forestry use (CLI)	H	H	O-H	O-H	H	H	L
Wildlife use (CLI)	N	O-L	O-L	O-H	O	H	L
Recreational use (CLI)	N	O-L	O-L	O-H	H	H	L
Engineering use	N	O-L	O-H	O	O	O	O

Respondent Group: Reg, Regional Foresters; Sil, Silvicultural Foresters; Ind, Industrial Foresters; Inv, Forest Inventory; Pro, Forest Protection; Fir, Fire Research; Tim, Timber Management.
Rating Levels: O, Not used; L, Low usefulness (Classes 1,2); M, Moderately useful (Class 3); H, Highly useful (Classes 4,5).

groups for map displays of secondary derived information. On the other hand, regional foresters are fairly uniform in having moderate to high regard for map displays of original data. In contrast, silvicultural foresters are alone in showing uniformly high preference for site specific information.

In general, these results indicate that Manitoba users of site classification information are prepared to derive this information from maps as well as from more site-specific sources. In fact, the consensus in favour of forest site maps at sufficiently large scale suggests that many users would be satisfied to obtain most of their site information from maps if such maps were available. The operating rationale may to a large extent be that field foresters and silviculturists do not have the time, and often not the expertise, to make the needed interpretations presented by the site classifiers in tabular or written form (Oswald, pers. comm.).

Future Needs

Respondents uniformly indicated a greater need for more site classification information in the immediate short term (1 to 5 years) than over the longer term (5 to 20 years). And although these results undoubtedly depended on the number of respondents from particular Forest Sections, sections with the greatest potential for industrial expansion as indicated by estimated wood surplus (Ondro and Williamson 1984) tended to receive the greatest short-term emphasis.

Conclusions

The results of the user information needs questionnaire strongly suggest that any unified site management classification system proposed for use in Manitoba should involve both mapping and site-specific approaches so that different users can identify and deal with their own key problem areas. Moreover, the results of the questionnaire support the need for a continued technology transfer process, probably very similar to that described by Jones (1985), and based on guidebooks such as those by Corns and Annas (1986) and Jones et al. (1983), as an integral part of any future site classification program for Manitoba.

Acknowledgments

Particular thanks are due Mr. R. Waldron and Dr. I. Corns of Forestry Canada, Northern Forestry Centre, Edmonton, for authorization of support funding. Thanks are also due to Dr. Richard Sims and the reviewers for helpful comments and criticism.

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Forest site classification in Alberta: its evolution and present status

by Ian G.W. Corns[1]

Abstract

The early history of forest site classification in Alberta is briefly reviewed. The major site classification effort, the biogeoclimatic ecosystem classification, and its progress over the past fifteen years is discussed. Available forest ecosystem and soil survey information was combined with other available information to produce a field guide with interpretations for forest management for one area in west-central Alberta. Similar field guides are in preparation. The obstacles to implementing a site classification are discussed, as are opportunities for using new information systems technologies.

Key words: Alberta, biogeoclimatic classification, forest ecosystems, forest site classification, site description.

Résumé

L'auteur donne un bref compte rendu des origines de la classification des sites forestiers en Alberta. Il examine les efforts considérables entrepris pour effectuer une classification des sites, l'établissement d'une classification de l'écosystème biogéoclimatique et sa progression durant les quinze dernières années. Les renseignements disponibles sur l'écosystème forestier et les relevés pédologiques d'une région du centre-ouest de l'Alberta ont été combinés à d'autres données pour produire un guide de cette région comportant des interprétations en matière d'aménagement forestier. D'autres guides de ce type sont en préparation. L'auteur aborde ensuite les difficultés inhérentes à la mise en ordre de la classification des sites ainsi que les possibilités d'utiliser les nouvelles technologies de systèmes d'information.

Mots clés : Alberta, classification biogéoclimatique, classification des sites forestiers, description du site, écosystèmes forestiers.

Introduction

In recent years in Canada a greater appreciation of the value of forested land by a variety of potential users has intensified interest in ecosystem classification, evaluation of variation in forest site productivity, and inventories of rapidly changing landscapes. Early forest-site research in the boreal forest of Alberta, Saskatchewan, and Manitoba fell behind other parts of Canada and the United States mainly because only recently (the last 35 years in Alberta) has any real utilization demand been put upon that forest region. The growing concern that forest resources are now being depleted too rapidly or are being managed in a less than optimal manner has prompted the search for means to utilize the forest resource most effectively while maintaining its productivity through management and planning.

Some of the earliest work in the Alberta boreal forest was done by Brinkman (1931, 1936), who used lichens and mosses as site indicators. Later Smithers (1956) assessed site productivity in dense lodgepole pine stands at the Kananaskis Experimental Forest in Alberta.

The first forest land classification or policy for Alberta was implemented in 1948. It delineated land to be used for forestry (the "green area") from land to be used for agriculture (the "white area"). Areas for settlement were defined on the basis of exploratory soil survey, ground and aerial observations.

As elsewhere in much of Canada, the Canada Land Inventory (CLI) land capability classification for forestry was undertaken for much of Alberta in the 1960s. This was followed by the similar Alberta Land Inventory (Archibald *et al.* 1979) in the mid to late 1970s, conducted predominantly on forest lands north of those inventoried by CLI. The Phase 3 forest inventory (Alberta Forestry Lands and Wildlife 1985) initiated in 1972 included a subjective rating of forest sites for each stand as fair, medium or good on the basis of a site index from height-age curves.

Duffy (1964) used multiple-regression techniques to find relationships between site factors and growth of lodgepole pine in the Alberta foothills. Duffy (1965) developed a forest-land classification for the Mixedwood Section of central Alberta on the basis of differences in soil parent material and soil-moisture status as they influence white spruce site index (Figure 1). Dumanski *et al.* (1973) evaluated the productivity of lodgepole pine forests using soil-survey maps for the Hinton-Edson area. Lesko and Lindsay (1973) related lodgepole pine and white spruce site index within fifteen forest types to soils in the Chip Lake map area in west-central Alberta and more recently, Corns and Pluth (1984) assessed vegetational indicators in forest growth prediction also for this region. La Roi and Pluth (1986) related white spruce and lodgepole pine site index to soil and vegetation properties in forests of western Alberta. In addition to formal site classification, earlier descriptions of vegetation distribution in northern and northwestern Alberta have been made by Lewis *et al.* (1928), Dowding (1929), Raup (1933, 1934, 1946), Moss (1953, 1955), Moss and Pegg (1963), La Roi (1967), Achuff and La Roi (1977) and Corns and La Roi (1976, 1983).

The major Alberta site classification initiative has been the undertaking of the biogeoclimatic classification of Alberta's forests. A intended three-year project was initiated by Mr. J. Soos of the Alberta Forest Service (AFS) in 1976 with project leadership provided by the Canadian Forestry Service (CFS) and operating funds by the AFS. The project was meant to facilitate site-specific forest management and had the following objectives (Krumlik *et al.* 1978):

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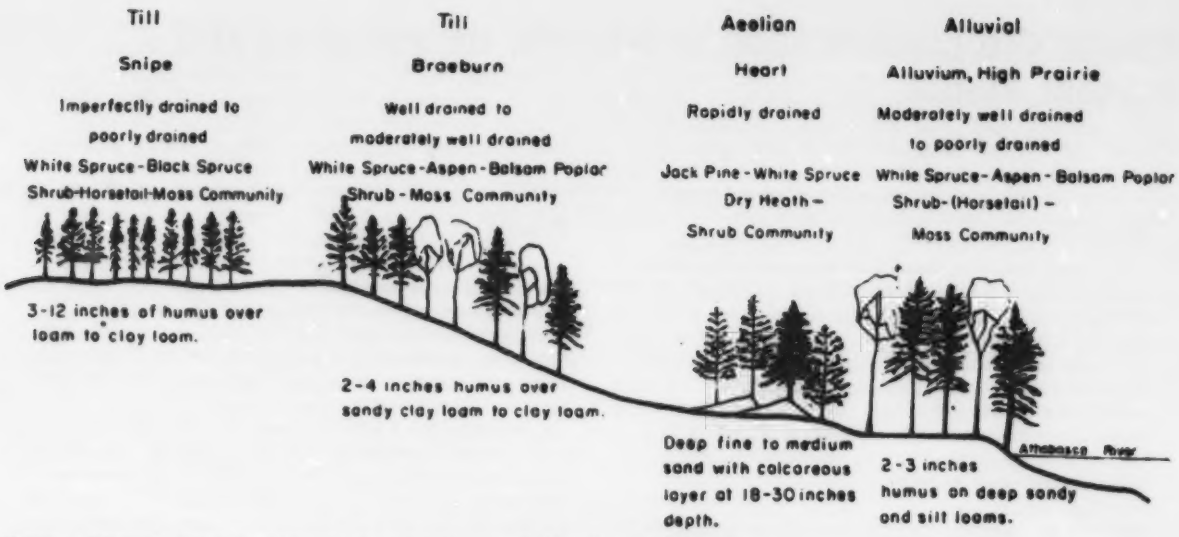

Till
Snipe
Imperfectly drained to poorly drained
White Spruce-Black Spruce Shrub-Horsetail-Moss Community
3-12 inches of humus over loam to clay loam.
Till
Braeburn
Well drained to moderately well drained
White Spruce-Aspen-Balsam Poplar Shrub-Moss Community
2-4 inches humus over sandy clay loam to clay loam.
Aeolian
Heart
Rapidly drained
Jack Pine-White Spruce Dry Heath-Shrub Community
Deep fine to medium sand with calcareous layer at 18-30 inches depth.
Alluvial
Alluvium, High Prairie
Moderately well drained to poorly drained
White Spruce-Aspen-Balsam Poplar Shrub-(Horsetail)-Moss Community
2-3 inches humus on deep sandy and silt looms.
Athabasca River

Figure 1. Schematic section of forest and soil relationships near Smith, Alberta (Duffy 1965).

- to classify Alberta sites within biogeoclimatic zones and to produce a zonation map at a scale of 1:1 500,000;
- to produce a classification of the forest ecosystems of Alberta;
- to analyze forest-environment relationships;
- to provide basic information on the forest ecosystems in terms of their structure, ecological characteristics, and potential productivity; and
- to promote application of this classification system in forest management practices and research programs.

The biogeoclimatic method of Krajina (1965, 1969) and his students was initiated in Alberta because of the apparent success and growing acceptance of the approach in British Columbia. The first project leader, Dr S. Kojima did graduate work with Dr. Krajina. Between 1977 and 1980, biogeoclimatic zones were mapped and component forest ecosystems described from 439 sample plots throughout the province.

Between 1980 and 1983 project leadership was assumed by the AFS. The field work was done mainly by the Resource Evaluation and Planning branch of Alberta Energy and Natural Resources. It focused on smaller areas — one National Topographic Series (NTS) map sheet or less — than the earlier biogeoclimatic work, which aimed at producing an ecological zonation at small scale for the entire province.

In 1982, with the arrival of Dr. R.M. Annas as Ecology Manager for the AFS Research Branch, another cooperative project with CFS was initiated to synthesize a large amount of ecological sample plot data into a field guide format. Relevant forest ecological and reconnaissance soil survey work done prior to the biogeoclimatic project was used. The area chosen encompassed three NTS map sheets and part of a fourth in an area that now includes land within six forest management agreement areas, managed by forest companies operating there (Figure 2). The proposed field guide had two main objectives:

- to classify and describe ecoregions (ecological zones) and their component ecosystems within the west-central Alberta study area (Figure 2) with respect to their floristic composition, environmental characteristics, successional relationships and forest productivity; and
- to provide a framework for forest management interpretations for the described units.

All relevant sources of vegetation, soils, and climate information available at the date of preparation of the guide were consulted, and as possible, incorporated into the interpretations. The *Field Guide to Forest Ecosystems of West-Central Alberta* was published in 1986 (Corns and Annas 1986).

In 1986 the biogeoclimatic classification of the Bow-Crow and Rocky-Clearwater forests in southwestern Alberta (Figure 2) was initiated by the AFS with funding from the Canada-Alberta Forest Resource Development Agreement. More than 500 sample plots were established in the area. The plots included full descriptions of soils, stand and site conditions associated with mature forest stands of more than 60 years of age. A sample page layout from the Sivak field guide (in preparation) appears in Figure 3.

Concurrent with the biogeoclimatic program was the provincial ecological land classification (ELC) program which conducted ecological inventories on a 1:100,000 scale (e.g. Dutchak 1984) that were focused on client needs — usually other than for forest management. Because of the similarity of the biogeoclimatic and ELC map products at the uppermost hierarchical levels (i.e., biogeoclimatic zones and ecoregions), the Alberta government decided to publish only one (*The ecoregions of Alberta*; Strong and Leggatt 1981), because of the more advanced status of the ecoregions work. The Strong and Leggatt (1981) map was published at 1:1 500,000 scale and is similar to an unpublished draft of the biogeoclimatic zonation of the provinces and to the Forest Regions of Canada map (Rowe 1972). This background work was meant to stratify Alberta's environmentally diverse landscapes into climatically, physiographically and vegetationally similar regions as a basis for understanding land relationships as well as a framework for more intensive future work. Other provincial map products include the Natural Regions of Alberta (1:5,000,000; Alberta Recreation

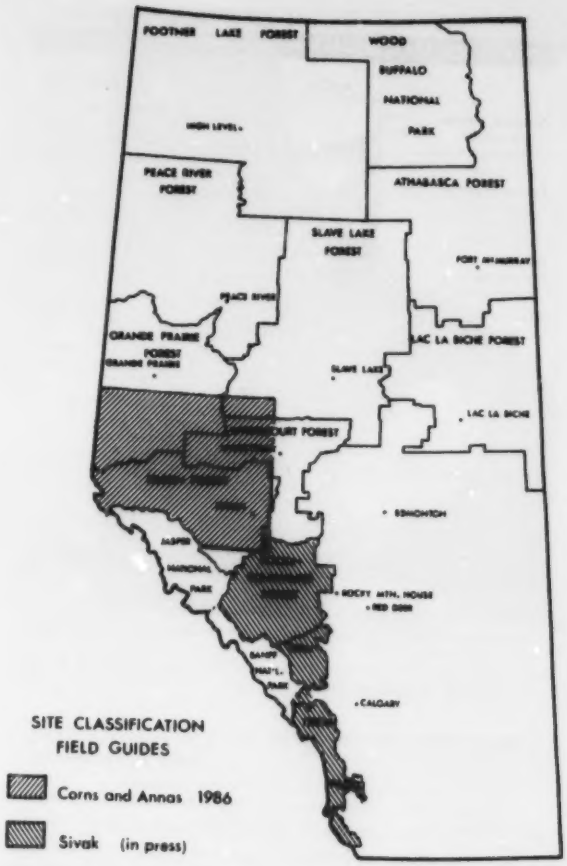


Figure 2. Alberta areas covered by site classification field guides.

and Parks, no date), Agro-Climatic Areas of Alberta (1:2,500,000; Bowser 1967) and the Physiographic subdivision of Alberta (1:1,500,000; Pettapiece 1986).

Most of the early site classification work in Alberta was local. Studies focused on vegetation, soils, landforms or combinations of these. The early studies provided background knowledge useful in subsequent regional ecosystem classification studies.

Methods

Methods employed in the Corns and Annas (1986) and Sivak studies mentioned above are similar. In both, there was an attempt to map biogeoclimatic zones or ecoregions and to describe their component forest ecosystems with respect to vegetation, soils, landform, environment, productivity and succession.

Zone or Ecoregion Mapping

During the field season, an aerial reconnaissance was carried out by fixed-wing aircraft and helicopters, while ground examinations were conducted along roads within the study area. Preliminary ecoregion boundaries were noted on 1:250,000 maps. Although the ecoregions grade slowly into each other over a distance of several kilometres, especially in eastern parts of the study area, the Boreal ecoregions could usually be separated from the air on the basis of canopy cover of tree species in upland sites; however, lodgepole pine is so pervasive (often to the exclusion of other tree species in the canopy) in the Upper Boreal Cordilleran (UBC) and Subalpine (SA) ecoregions, that determining the UBC/SA boundary from the air is extremely difficult. Nomenclature for the ecoregions was adapted from an early draft of the Ecoregions Working Group (1989). The SA boundary is based on the general presence or absence of typical subalpine plant species in forest stands. Boundary points were established on the ground; the boundary was drawn on the map by extrapolation, mainly along elevational lines. Map boundaries were checked and adjusted from visual interpretation of LANDSAT color infrared images.

Corns and Annas (1986) also relied on other study boundary lines. For example, they cite Krumlik *et al.* (1982) on the Berland Forest Management Area and The Alberta Resource Evaluation and Planning Branch studies of the Coal Branch area south of Hinton in west-central Alberta (Robertson *et al.* 1984)). The final ecoregion mapping scale was 1:500 000 for the west-central Alberta study area.

Plot Sampling and Classification

The 0.04-ha sample plots were selected from forest cover maps and aerial photographs within well-developed, homogeneous forest stands on a variety of soils and landforms. The sample plots were placed subjectively to best represent particular soil and vegetation conditions. Plot location and general physiography (elevation, slope gradient and aspect, topographic position, relief shape, and landform) were recorded on field sheets. Soils were described according to the Canadian System of Soil Classification (Canada Soil Survey Committee 1978). Vegetation was sampled in a manner compatible with Braun-Blanquet's (1932) methods and those described by Walmsley *et al.* (1980). Data from all studies were computer-coded in the same format to facilitate comparison. Classification in most studies was done by tabular comparison (Mueller-Dombois and Ellenberg 1974) of similar plots within each ecoregion by means of computer-generated vegetation and environment tables. Some studies (such as Sivak 1988) have used the Cornell Ecology Series programs (TWINSPAN, DECORANA; Hill 1979a, b). Sivak (1988) also has used the COENOS program developed by Ceska and Roemer (1971) as aids to classification.

In addition, all sample plots included forest mensurational data. Heights and diameters were estimated for all trees in the plot. Ages were determined for 4 to 10 trees per plot. One hundred and thirty-seven plots had detailed stem analysis. Site index was determined for all plots by species on the basis of dominant and codominant trees. The stand volumes and mean annual increment in total volume (MAI) were also determined for most plots.

Ecoregion-Biogeoclimatic Zone and Ecosystem Descriptions

The ecological moisture regime (hygrotope) indicates the relative moisture available for plant growth on the basis of the whole growing season rather than any particular time. The hygrotope is influenced mainly by slope position, texture, internal drainage, and slope gradient. It is generally assessed by means of these factors (especially soil drainage) in conjunction with the presence of characteristic species in the ecosystem association, although it can be

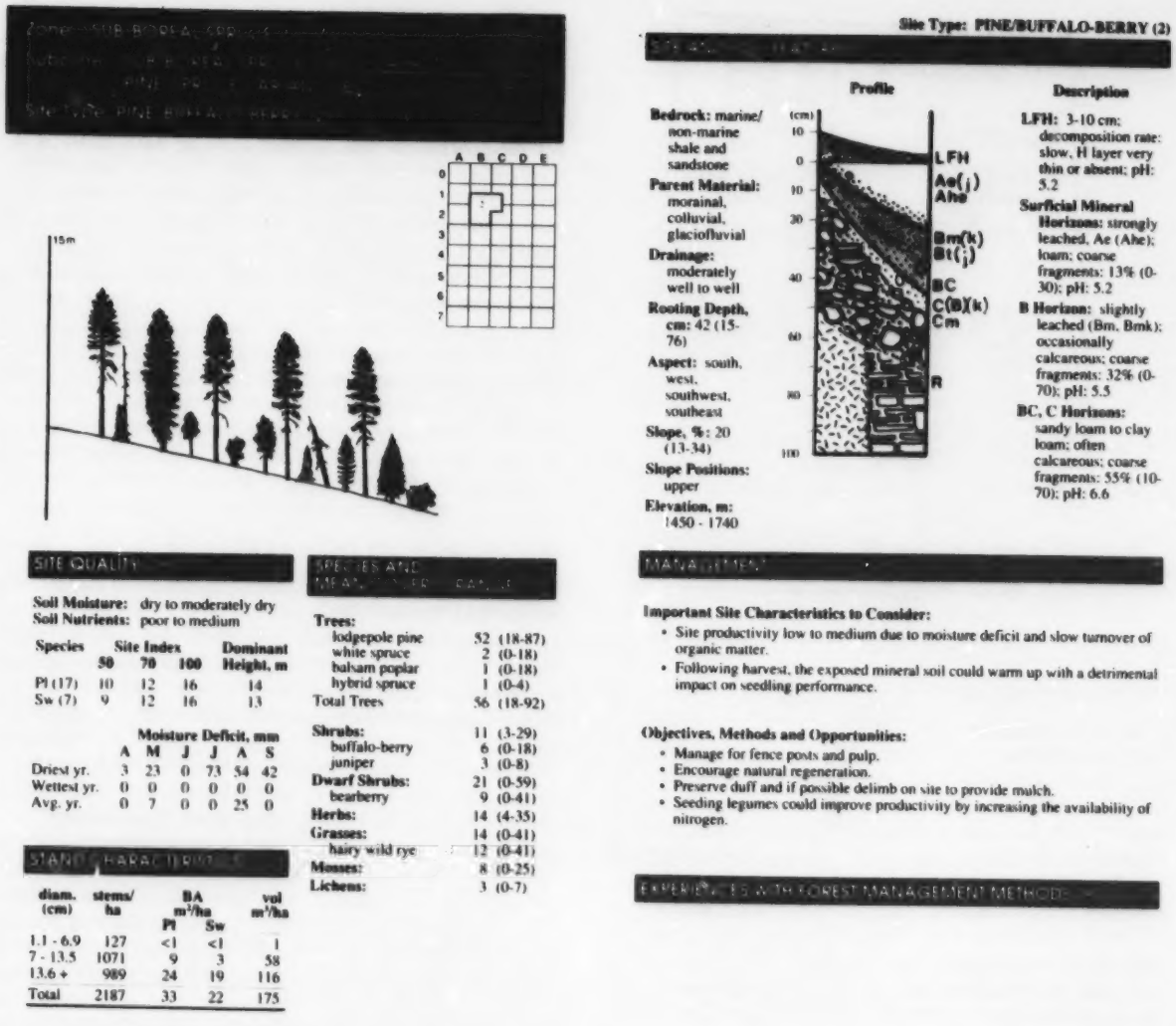

Site Type: PINE/BUFFALO-BERRY (2)
Profile
Description
Bedrock: marine/non-marine shale and sandstone
Parent Material: morainal, colluvial, glaciofluvial
Drainage: moderately well to well
Rooting Depth, cm: 42 (15-76)
Aspect: south, west, southwest, southeast
Slope, %: 20 (13-34)
Slope Positions: upper
Elevation, m: 1450 - 1740
LFH
Ae(j) Ahe
Bm(k) Bt(j)
BC
C(B)(k) Cm
R
LFH: 3-10 cm; decomposition rate: slow, H layer very thin or absent; pH: 5.2
Surficial Mineral Horizons: strongly leached, Ae (Ahe); loam; coarse fragments: 13% (0-30); pH: 5.2
B Horizon: slightly leached (Bm, Bmk); occasionally calcareous; coarse fragments: 32% (0-70); pH: 5.5
BC, C Horizons: sandy loam to clay loam; often calcareous; coarse fragments: 55% (10-70); pH: 6.6
SITE QUALITY
Soil Moisture: dry to moderately dry
Soil Nutrients: poor to medium
Species | Site Index 50 70 100 | Dominant Height, m
Pl (17) 10 12 16 14
Sw (7) 9 12 16 13
Moisture Deficit, mm
A M J J A S
Driest yr. 3 23 0 73 54 42
Wettest yr. 0 0 0 0 0 0
Avg. yr. 0 7 0 0 25 0
Trees:
lodgepole pine 52 (18-87)
white spruce 2 (0-18)
balsam poplar 1 (0-18)
hybrid spruce 1 (0-4)
Total Trees 56 (18-92)
Shrubs: 11 (3-29)
buffalo-berry 6 (0-18)
juniper 3 (0-8)
Dwarf Shrubs: 21 (0-59)
bearberry 9 (0-41)
Herbs: 14 (4-35)
Grasses: 14 (0-41)
hairy wild rye 12 (0-41)
Mosses: 8 (0-25)
Lichens: 3 (0-7)
MANAGEMENT
Important Site Characteristics to Consider:
• Site productivity low to medium due to moisture deficit and slow turnover of organic matter.
• Following harvest, the exposed mineral soil could warm up with a detrimental impact on seedling performance.
Objectives, Methods and Opportunities:
• Manage for fence posts and pulp.
• Encourage natural regeneration.
• Preserve duff and if possible delimb on site to provide mulch.
• Seeding legumes could improve productivity by increasing the availability of nitrogen.
diam. (cm) | stems/ha | BA m²/ha Pl Sw | vol m³/ha
1.1 - 6.9 127 <1 <1 1
7 - 13.5 1071 9 3 58
13.6 + 989 24 19 116
Total 2187 33 22 175

Figure 3. A sample page layout from the *Field Guide to Forest Ecosystems of Southwestern Alberta* (Sivak, in preparation).

characterized on the basis of either site or vegetation attributes.

The soil nutrient regime (trophotope) indicates the relative available nutrient supply for plant growth (with emphasis on soil rooting zone pH and exchangeable cations). Because nutrient abundance is not quantified and the relative abundance of individual nutrients is not indicated, use of the trophotope presents a problem. It is nevertheless a useful factor to determine, using aids such as those provided by Walmsley *et al.* (1980). The nutrient regime is influenced by a number of factors, including bedrock source, soil texture, organic matter content, humus form, soil reaction (pH), and others.

General descriptions of each ecoregion and ecosystem are supplemented by moisture and nutrient regime grids and cross-sections that outline the characteristic tree species and soil parent materials. The soil names are explained in the Canada Soil Survey Committee (1978) manual.

The moisture-nutrient grid, adapted from the edatopic grid of Krajina (1969), shows the relative modal moisture and nutrient status of the ecoregions and ecosystems (Figure 4). The descriptions of moisture and nutrient regimes are adapted from Walmsley *et al.* (1980).

The Field Guide

Although the ecoregion-biogeoclimatic zone and ecosystem sampling and description methods of Corns and Annas (1986) are similar to much of the earlier Alberta work, there are a number of differences. Corns and Annas (1986) used data pooled from approximately 900 sample plots from studies by Corns (1978, 1983), Krumlik *et al.* (1978, 1979, 1982), Krumlik and Johnson (1978, 1979) Lesko and Lindsay (1973), Nemeth *et al.* (1980) and Robertson *et al.* (1984). Although the work of Lesko and Lindsay (1973) is from the Chip Lake Map Area next to the southeast corner of the study area (Lower Boreal Cordilleran ecoregion), many of the

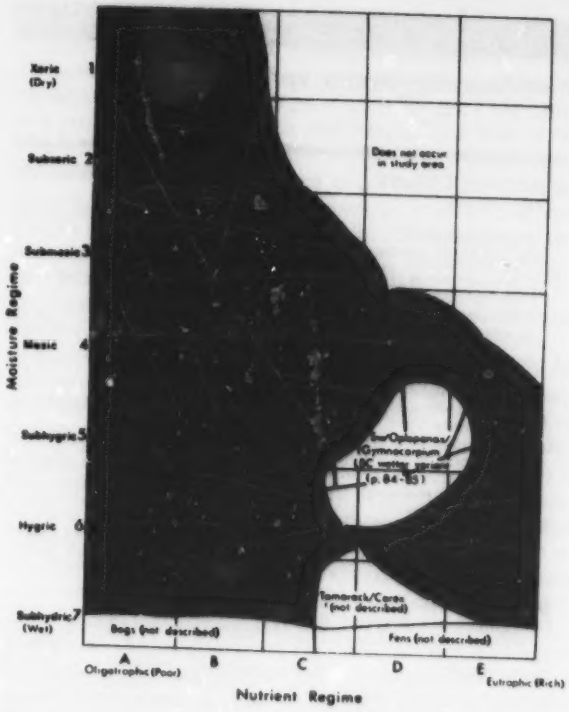


Figure 4. The edaptopic grid for the Lower Boreal Cordilleran Ecoregion (Corns and Annas 1986).

sample plots are similar to the lower elevations of the study area farther north and are included in corresponding plot groupings for the study area to provide additional replication. Corns and Annas (1986) use a moisture-elevation ordination to indicate the common altitudinal ranges of the ecosystems described, many of which cross ecoregion boundaries. A dichotomous key to the major ecosystem associations is given. Most of the understory species listed are illustrated later in the Field Guide in a section to facilitate identification of common forest plants of west-central Alberta. Aids to soil property descriptions are given for ecological moisture regime, mineral horizon descriptions, forest humus horizons and humus types, texture, and drainage. Landforms and other terms are defined in a glossary (Corns and Annas 1986).

A small table of forest management interpretations is presented at the bottom of the first page of each association description. The interpretations are made for the ecosystem associations and reconnaissance soil survey mapping units. Interpretations are based on a variety of sources, including reconnaissance soil survey data (Dumanski *et al.* 1972; Twardy and Corns 1980; Knapik and Lindsay 1983), available forest ecological information and observations by operational foresters and the authors. Quantitative data were not available for many interpretations as well as for some ecosystem associations and soil map units. In these instances data from similar environmental or ecological situations were extrapolated. Interpretations were made for a variety of attributes significant for forest management: potential productivity in site index (SI) and MAI for dominant species; season and method of harvest; site preparation intensity; soil compaction hazard; soil puddling hazard; soil water erosion hazard; reforestation species selection, method, and limitations; seedling frost heave hazard; type and severity of vegetational competition; windthrow hazard; and snowshoe hare damage hazard. A sample page layout from the Corns and Annas (1986) Field Guide appears in Figure 5.

Summary tables used in making interpretive evaluations are included in the management interpretations section of the Field Guide (Corns and Annas 1986). By means of these tables, it is possible to determine management interpretations on a site-specific basis, as well as on the basis of the more generalized ecosystem associations or soil map units. Caution should be exercised in applying interpretations to situations where identification of the ecosystem association or soil properties association is a problem. These interpretations should not supersede any knowledge gained by the forest manager through systematic observation and experience. It is thus important to evaluate sites individually where site-specific information is desired and to revise management interpretations accordingly. The ratings should be regarded as provisional until more detailed quantitative information is available.

Results

The biogeoclimatic ecosystem classification program in Alberta has yielded a number of publications and unpublished file reports. Early work was presented in several CFS file reports (Kojima and Krumlik 1977; Krumlik *et al.* 1978a, 1978b; Krumlik and Johnson 1978, 1979; Nemeth *et al.* 1980) describing annual project activities and preliminary classifications. Some of these data were subsequently synthesized by Kojima (1980) in a 1:1,000,000 scale map of the biogeoclimatic zones of southwestern Alberta. Forested plant associations of the subalpine regions of Alberta were described by Kojima (1983, 1984).

Staff at the provincial Resource Information Branch of Alberta Forestry, Lands and Wildlife have prepared a number of reports in support of and complementary to the site classification program in Alberta. The Ecoregions of Alberta, mapped at 1:1,500,000 by Strong and Leggatt (1981) and presently being revised and updated with the inclusion of ecodistricts (subdivisions of ecoregions), provide a suitable provincial framework for subregional studies. Examples of such studies are Annas *et al.* (1983) and Robertson *et al.* (1984), Archibald *et al.* (1984), Bentz *et al.* (1984) and Archibald (1986).

As noted above, forest site classification work in the Bow-Crow and Rocky-Clearwater Forest Districts in southwestern Alberta was completed by Dr. B. Sivak of the AFS Research Branch. He classified forest ecosystems on the basis more than 500 sample plots and presented the information in field manual format (Figure 3). A draft field guide was tested by field foresters during the summer of 1991; its publication is expected in 1992 or 1993.

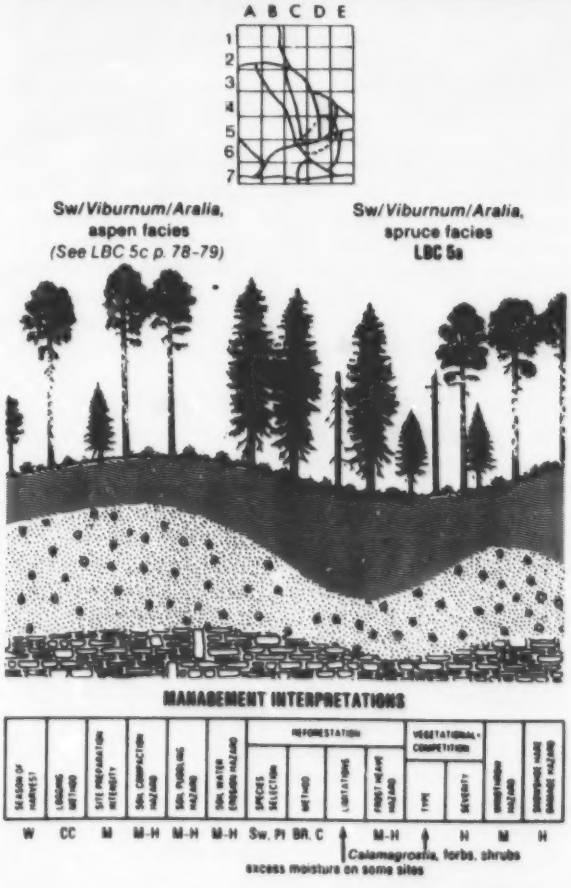
Discussion

Classification

The Alberta site classification system is adapted from the biogeoclimatic system developed in British Columbia by Krajina (1965, 1969) and his students. The classification system used in the Field Guide (Corns and Annas 1986) serves as an example. This hierarchical classification places the ecoregion at the top level. An ecoregion is a geographical

LBC 5a

Sw/*Viburnum/Aralia*, spruce facies
(white spruce/mooseberry/wild sarsaparilla)



Sw/*Viburnum/Aralia*, spruce facies

CHARACTERISTIC SPECIES:
(with % cover)

A. *Picea glauca* (51)
Populus tremuloides (7)

B. *Viburnum edule* (13)
Rosa acicularis (5)
Ribes lacustre (1)
Amelanchier alnifolia (+)[1]

C. *Aralia nudicaulis* (14)
Cornus canadensis (10)
Linnaea borealis (9)
Rubus pubescens (7)
Mitella nuda (7)
Mertensia paniculata (4)
Calamagrostis canadensis (3)
Maianthemum canadense (1)
Petasites palmatus (1)
Galium boreale (1)
Pyrola asarifolia (1)
Actaea rubra (+)
Epilobium angustifolium (+)
Orthilia secunda (+)

D. *Hylocomium splendens* (20)
Pleurozium schreberi (12)
Ptilium crista-castrensis (11)

ENVIRONMENT:

MOISTURE REGIME (MODAL):
Mesic to subhygric (4–5)

pH REGIME (MEAN):
Humus: 3.2–6.0 (5.0)
Mineral: 3.9–7.7 (5.6)

ELEVATION RANGE (MEAN):
575–1060 (831) m

PERCENT SLOPE GRADIENT (MEAN): 0–37 (4)

ASPECT: Variable (level to northerly)

SOIL SUBGROUPS: Orthic, Gleyed, and Brunisolic Gray Luvisols

ASSOCIATED SOIL UNIT/ ASSOCIATION: BKM, DVS, DON, EDS, LDG, LDM, NMP, SIP, TRC

SOIL DRAINAGE: Moderately well to imperfectly

LANDFORM: Morainal, lacustrine

PRODUCTIVITY:

MAI (MEAN):
2.1–6.7 (4.8) m³/ha/yr

SI at 70 (MEAN): Sw 14–21 (19) m
Pl 19–31 (23) m

NUMBER OF PLOTS: 15

SUCCESSIONAL RELATIONSHIPS

These forests are successionally mature. *Abies* sp. may form a significant component of stands over 100 years. Some of the forests may have succeeded from aspen forests (e.g., Sw/*Viburnum/Aralia*, aspen facies) over a period of 50 to 100 years.

SIMILAR ASSOCIATIONS:

This association is most similar to the Sw/*Viburnum/Rubus pubescens* association, which is somewhat drier. Stands with sparse shrub and herb cover may be transitional to the Sw/*Hylocomium* association. It is similar to the *Picea glauca/Viburnum edule/Rubus pubescens* association of Archibald et al. (1984).

COMMENTS:

When the forest cover is harvested, vegetation cover (especially *Calamagrostis canadensis*) may be expected to increase greatly, competing with tree seedlings.

[1] + indicates less than 0.5% cover.

Figure 5. A sample page layout from the Corns and Annas (1986) field guide.

area with a distinctive, mature ecosystem and a specified edaphic variation caused by a given regional macroclimate. It is similar to the ecoregion of Strong and Leggat (1981), the forest section of Rowe (1972), and the biogeoclimatic subzone of Krajina (1965), Annas and Coupé (1979), and Pojar (1983). The terminology used is consistent with that used by the Ecoregions Working Group (1989) for the Ecoclimatic Regions of Canada. An ecoregion map at a 1:500,000 scale is included with the Field Guide.

The Guide describes ecosystem associations within ecoregions. An ecosystem association is an abstract taxonomic unit. It is defined as all land areas with the potential of supporting plant communities with similar successional development belonging to the same plant association. More than one soil family may be represented. The ecosystem association resembles the plant association of Braun-Blanquet (1932) and the habitat type of Daubenmire (1952). Individual ecosystem association descriptions are the focus of this Field Guide (Corns and Annas 1986).

Phases of ecosystem associations are recognized to facilitate more precise management interpretations and are distinguished on the basis of differences in slope class, aspect, soil, climate, or some other feature of soil or vegetation. Phases are not formal taxonomic categories. A facies is a form of ecosystem association dominated by a given tree species. For example, in the *Picea glauca/Viburnum/Aralia* ecosystem association similar sites may support pure stands of aspen, white spruce, paper birch, or pine, depending on stand origin. Thus the ecosystem association above has four different facies determined by the dominant tree species. A biogeocoenose is the smallest ecosystem recognized in the field in terms of this classification; its size is determined by the extent of the plant community and the associated soil polypedon. It corresponds to the ecoelement in the Canada System of Ecological Land Classification (Wiken 1986).

Units described in Corns and Annas (1986) are the ecoregion, ecosystem association, and in a few cases, the ecosystem association phase.

Classification vs. Mapping

Like the biogeoclimatic classification used in British Columbia, and the Forest Ecosystem Classifications used in Ontario (Jones *et al.* 1983, Sims *et al.* 1989), the Field Guide is a taxonomic system which identifies the site units in the field by using a key as opposed to being a cartographic system which maps the site units. Such an approach classifies and describes the various forest ecosystems or site types occurring in an area in a cost-effective way. Such classifications also serve as a good base for site-specific forest management prescriptions at the field level but are less satisfactory for the inventory forester or silviculturist who needs to quantify the areal extent of productivity or treatment units.

Mapped site classifications are generally preferred by the user and have the advantage of being able to relate the site units to other mapped information by means of overlays or a geographic information system (GIS). However, site mapping at the scales desired by foresters (1:10,000–1:25,000) is very expensive and cannot usually be justified for large areas.

There is potential to tie point-source observations and interpretations from a taxonomic site classification such as the biogeoclimatic system to some cartographic product such as reconnaissance soil survey through use of extended legends and a GIS to produce interpretive maps. This was done by Corns and Annas (1986) by means of a GIS to produce 1:250,000 scale maps of the various management interpretations made in the Field Guide for the ecosystem units and the soil mapping units. The small scale of these maps, however, limits their utility.

The NAIA project, a joint research venture between the Alberta Research Council (ARC), Hughes Aircraft of Canada Ltd., Spatial Data Division, Forestry Canada and a number of forest companies, is addressing the problem of the usual lack of site classification maps. An experienced forest ecologist can generally estimate with reasonable accuracy the forest ecosystem type occurring at a particular site with knowledge gained from personal experience, reconnaissance soil survey maps and reports, forest inventory maps, topographic maps and a regional forest ecosystem field guide. The intent of the NAIA project is to integrate the various map themes mentioned above in a GIS environment through the use of expert system rules from site classification field guides and experienced field ecologists, and to assign ecosystem or site types to integrated map units at scales from 1:20,000 to 1:50,000, together with some estimate of the likely reliability of the prediction. The concept is being tested on pilot areas with site types mapped at a scale of 1:20,000 in west-central Alberta. The types, reliability, scale and map projection of background sources of information will vary depending on the geographic area. The ultimate objective of the NAIA technology is thus to synthesize available information and knowledge into a comprehensive decision support system in the best possible way.

Concurrently with NAIA, the Forest Resources Program at the Northern Forestry Centre (NoFC) of Forestry Canada in Edmonton is undertaking the development of several decision support systems (DSS) for Boreal Mixedwood management. The DSS will eventually address both timber and non-timber (especially wildlife) values, but will focus on silvicultural modules initially. The intent is that the NAIA project will provide the spatial dimension to the stand-based DSS modules developed at NoFC.

There have been only a few Northwest Region studies that have developed empirical relationships between site factors and some measure of productivity (Duffy 1964, Corns and Pluth 1984). By combining factors derived from aerial photographs or satellite imagery with those obtained from reconnaissance soil survey maps, it may be possible to predict site productivity on an areal basis more accurately than in the past and thus satisfy needs of the inventory forester. Methods for integrating empirical models with DSS such as the NAIA and NoFC projects will be explored in future.

Technology Transfer

In the past, government agencies have produced reports filled with information valuable to prospective clients. Often, however, there has been no adequate technology transfer to ensure the work is optimally used, with the result that such reports are underutilized and sometimes forgotten.

The importance of technology transfer in site classification has been demonstrated in British Columbia and Ontario, through their Biogeoclimatic and Forest Ecosystem Classification programs. In Alberta, during the evolution of the biogeoclimatic program, several field workshops were conducted for operational foresters, to familiarize users with the system. After the publication of the *Field Guide to Forest Ecosystems of West-Central Alberta* (Corns and Annas 1986), Forestry Canada has conducted numerous two-day summer training courses in west-central Alberta. The courses normally consist of a two- to three-hour office orientation and exercise using the field guide and soil survey reports for the area concerned, followed by 1.5 days spent keying-out and interpreting soil profiles and ecosystems in the field. The desirability of longer training sessions is acknowledged but was not possible because of the busy field schedules of the trainees.

The responses to the field workshops, the Corns and Annas (1986) Field Guide (the main user-oriented product to date) and a 22-minute video (Canadian Forestry Service 1988) have been mainly favorable, although at first site classification was slow to be adopted by forest companies. Several good reasons for this are outlined below.

- Site classification information in user-oriented format is still unavailable for most of Alberta.
- The site classification is not mapped (see discussion above).
- The user is still often not comfortable using a site classification — more training is necessary.
- It takes a long time to quantify management response to various treatments on a range of sites, and there may be scepticism of the authors' interpretations until these can be demonstrated to the users' satisfaction.
- Forest management in Alberta is still not intensive; historically, it has been often difficult for foresters to see the relevance of site classification information to their daily tasks until it could be demonstrated convincingly.
- There is no provincial requirement to use site classification as a basis for silviculture prescriptions as is done in British Columbia (Anonymous 1985).

During the past two years there has been a considerable increase in interest in forest ecosystem classification on the part of forest companies in the ForCan Northwest Region. There is a growing awareness of the value and necessity of managing land on the basis of its potentials and constraints. In Alberta, the Ecological Classification Task Force chaired

by the AFS and comprising mainly forest industry representatives, has voiced the need for extension of the forest ecosystem classification program to the parts of Alberta (mainly in the north) not covered by previous work. Funds have been identified under the upcoming Canada-Alberta Partnership Agreement in Forestry to continue forest ecosystem classification work.

Conclusions

There is a need for more work on the analysis of forest-environment relationships. The application of modern multivariate statistical analysis methods to the now very large data base, should greatly help to quantify trends in productivity and ecosystem dynamics expressed in more qualitative terms in reports and publications produced to date.

Forest management in Alberta is becoming rapidly more intensive, particularly with the sudden increase in aspen utilization for oriented strandboard and pulp. The development of the rationale for managing a mixedwood land base for a variety of species and benefits will undoubtedly involve an assessment of site potential and the desire for information to make such decisions in a well-informed fashion.

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Forest site classification activities in Northern Canada

by E. T. Oswald[1]

Abstract

Historically, site classification north of 60°N. Lat. includes related activities conducted by geologists over the last century, particularly the information presented on surficial materials. Ecological land classification provides a technique suitable for evaluating the capability of the land base to satisfy the requirements of various renewable resource sectors. Ecological Land Surveys that included an assessment of forest capability have been used over much of northern Canada. A forest inventory, or cover mapping, has been done for part of the forest environment. The demands on the forest resource are increasing, not only for the utilization of wood products, but also for recreational facilities, tourism, and wildlife habitat. Forest site classification based on ecological factors is essential to provide an informed basis for making resource management and utilization decisions. Some site classification techniques are discussed, and recommendations made in support of continuing classification and surveys for more intensive management and for the preservation and analyses of ecological reserves.

Résumé

Au nord du 60e parallèle, la classification des sites a toujours inclus des activités menées par les géologues au cours du siècle dernier, notamment les données sur les matériaux de surface. La classification écologique du territoire offre une technique permettant d'évaluer l'aptitude des terres à répondre aux exigences de divers secteurs des ressources renouvelables. Des relevés écologiques du territoire, qui comportaient une évaluation des possibilités forestières, ont été réalisés dans la majeure partie du nord du Canada. On a dressé un inventaire forestier ou une carte topographique de certaines parties du milieu forestier. Les demandes exercées sur les ressources forestières ne cessent d'augmenter, non seulement à l'égard des produits du bois, mais également à l'égard des installations récréatives, touristiques et des habitats fauniques. La classification des sites forestiers, fondée sur des facteurs écologiques, est un outil essentiel à l'obtention d'une base de données bien documentée, permettant de prendre des décisions en matière d'utilisation et de gestion des ressources. L'auteur examine certaines techniques de classification des sites et formule des recommandations en faveur d'une classification et de relevés permanents conduisant à une gestion plus intensive ainsi qu'à la conservation et à des analyses des réserves écologiques.

Introduction

Studies related to forest site classification in Canada north of 60°N. Lat. have been sporadic at best, largely due to the low esteem in which these forests are held by most relevant managers. Historically northern Canada has been, and for the most part still is, sparsely populated. Consequently, there has been little need for intensive renewable resource management. Also, transportation costs impact negatively on marketing any resource product.

The primary resource concerns in northern Canada since about 1850 have been for mineral and fossil fuel exploration and extraction. Geological explorations and mineral extractions have combined traditional prospecting and state-of-the-art technology. Any management of wildlife habitat during this period was mostly by native peoples, while much wildlife exploitation was done by fur traders. Steamboats in the Yukon used the accessible wood along the Yukon River and major tributaries for fuel; subsequently most forestry practices have continued to be directed towards local consumption, largely by the mining industry and as cord wood. The economy of the north has been governed chiefly by revenues from mineral extraction. However, limitations to mining during the past decade have shifted interests to other resource sectors, and brought about a need for a closer look at site classification and what it may offer for land and resource allocation and utilization.

Although the earlier surveys were mostly for purposes other than land, site, or forestry classification, some pertinent information was made available. Geological surveys led to descriptions of bedrock and surficial geology for many areas. Access was mostly along rivers during the summer, and dog teams during the winter (though a few geologists used horses) so that the surveys were done mostly in valleys. The construction of the Alaska Highway in 1942 provided access to the forested part of southern Yukon, and allowed investigations by botanists, ecologists, and agriculturalists of the vegetation, soils, climate, and forest cover. The roads to Yellowknife and Norman Wells in the Northwest Territories (N.W.T.) did not attract as many "naturalists" as the Alaska Highway, or other subsequent roads in the Yukon. Consequently early information on site classification from the N.W.T. is virtually non-existent. Aerial photography became available in the late 1940s and early 1950s, mostly through military testing missions. Very little documented use was made of this photography for land classification until more recent times.

This report is concerned with some of the preliminary work related to land and site classification. It reviews recent surveys, summarizes the current state of knowledge and offers some recommendations, mostly from a forestry perspective.

Land Resource Surveys

Early surveys related to terrain classification were conducted in relation to mineral exploration (Bostock 1973). Camsell (1936) was among the first to use air photographs, these being mostly oblique photos taken along a single flight line across southeastern Yukon and into the N.W.T. From these photos, he described the physiography and general vegetation. Bostock (1948) described and mapped the physiography of the Yukon. Hughes *et al.* (1969) described the

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glacial flow patterns. Raup (1934) explored and described the vegetation in relation to physiography from ground surveys, but later Raup and Denny (1950) used aerial photographs to describe the terrain and vegetation along the Alaska Highway. Jeffrey (1964) conducted a similar survey of southwest N.W.T.

On the basis of these early surveys of physiography and vegetation, later resource-related work was directed to areas of specific interest. With the use of information obtained from prospectors and ground surveys, the geology was described and mapped (see references in Hughes *et al.* 1972 and Pettapiece *et al.* 1978). Vernon and Hughes (1966) mapped the surficial geology of west-central Yukon. Day (1962) conducted a reconnaissance soil survey of part of south-central Yukon for the purpose of developing agricultural pursuits. The arctic climate was described by Weller and Bowling (1973), and climatic data for specific areas were often included in various resource classification, description, and mapping reports. Brown (1978) mapped the permafrost distribution.

Halliday (1937) and Rowe (1972) included northern Canada in their work on forest regions. Gairns (1968) mapped the forest resource of the Yukon, and Peaker (1968) and Hirvonen (1968) described the forest conditions in areas with the most promise for productive tree growth. Forest cover surveys were performed with large-scale photo sampling in the Yukon (Nielsen *et al.* 1979; Rymer 1986), and with conventional aerial photography of the Lower Liard District, N.W.T. (Department of Indian and Northern Affairs 1986). A reconnaissance inventory of forest volume and biomass for southern Yukon was conducted by Bonnor and Oswald (1988).

Site Classification

The first comprehensive approach to resource classification relevant to site classification was put forth by the Subcommittee on Biophysical Land Classification (Lacate 1969), and integrated base data inventories were addressed in a technical workshop (Romaine and Ironside 1979). The Arctic Land Use Research Program employed some of these guidelines in studies around Watson Lake, Yukon and in southwestern N.W.T. (Lavkulich 1973; Murray *et al.* 1973; Lavkulich and Walmsley 1974); the concepts were also utilized in some of the surveys conducted in preparation for the Mackenzie Valley gas pipeline (Crampton 1973; Zoltai and Pettapiece 1973; Hettinger *et al.* 1973; Reid 1974; Reid and Janz 1974). The anticipated need for hydro-electric power led to surveys of some watersheds (Robertson and Eliasen 1974), while continued interest in resource development led to studies in the Watson Lake area (Reid 1975).

The need for a renewable resource data base by the Canadian Forestry Service gave rise to the delineation and description of "ecoregions" (Oswald and Senyk 1977). The concepts of ecoregions differed somewhat from the regions advocated by Lacate (1969) in that the regions were units of the landscape influenced by a particular climate as reflected by the vegetation, while ecoregions were units of the landscape possessing a uniform physiography and supporting a particular vegetation pattern based on species composition under the influence of a particular climate. In essence, the physiography, vegetation, and climate are given equal weight for describing units in the ecoregion concepts. Other land classification systems are available (Corns and Annas 1986; Environmental Conservation Service Task Force, undated; Pojar 1983) which are correlated in Table 1. The classification information can be put into a computerized geographic information system (GIS) (Lee *et al.* 1978).

The probability of a pipeline or other petroleum-related development in northern Yukon, and the possible effects this would have on wildlife and related resources in the area proposed for an international park, sparked Parks Canada to support an ecological survey for most of the area north of the Ogilivie Mountains (Wiken *et al.* 1981). This survey employed concepts similar to the ecoregions and advanced the development of the Ecological Land Survey (ELS) system through the ecodistrict level. A similar study was conducted in the N.W.T. (Bradley *et al.* 1982).

The Lands Directorate embarked on a plan to describe and map the ecodistricts for all of Canada and put the data into a GIS (Senyk *et al.* 1988). Some studies followed the concepts of the ELS system in classifying areas for recreational development to the ecosection level (Senyk *et al.* 1981), but in some cases the resource components were not amalgamated into ELS units (Davies *et al.* 1983 a, b). The resource data for Kluane National Park Reserve obtained over several years by specialists in various fields was recently put together (Gray 1987), but additional correlation is necessary to present the information on a site-specific basis. A study was conducted within part of one ecoregion in the Yukon to classify the forested terrain (Oswald 1979) at the Ecosite level. The environmental assessment of the proposed Alaska Highway pipeline resulted in resource data being collected, some of which were pertinent to site classification (Orloci and Stanek 1979; Redpath 1979; Stanek 1980, 1982; Stanek and Orloci 1987).

Other recent work related to site classification includes a description of the forest communities in one ecoregion (Oswald and Brown 1986). As indicated by these later surveys, the vegetation requires a classification separate from the terrain, but correlated with it. Table 2 portrays a number

Table 1. Land classification systems performed by various agencies

ELS[1]	Alberta[1]	British Columbia[1]	Information[2]
Ecoprovince	Biogeoclimatic Reg.		
Ecoregion	Ecoregion	Biogeoclimatic Zone	Low
Ecodistrict	Ecosubregion	Biogeoclimatic Subzone	
Ecosection	Ecosystem Assoc.	Climatic Region	
Ecosite	Ecosystem Type	Ecosystem Assoc.	
Ecoelement	Biogeocoenose	Biogeocoenose	High

[1]Ecological Land Survey of the Canada Committee on Ecological Land Survey (Environmental Conservation Service Task Force); Alberta system is according to Corns and Annas (1986); British Columbia system is after Pojar (1983).
[2]Indicates the quantity of information about the site required to classify at each level.

Table 2. Vegetation classification systems utilized by various agencies.

California[1]	U.S. For Service[2]	Jones *et al.* & Stanek[1]	Alberta[1]	British Columbia[1]	Damman[1]
Formation					
Subformation					
Series	Series	Operational group	Ecosystem type		Forest types
Association	Habitat type[2]	Vegetation type	Facies	Ecosystem Association	Forest type
Phase					

[1]The California system is after Paysen *et al.* (1980).
The U.S. Forest Service system is according to Steele *et al.* (1983).
Jones *et al.* (1983) and Stanek (1980) have a similar system.
The Alberta system is according to Corns and Annas (1986).
The B.C. system is after Pojar (1983).
Damman's system for Newfoundland is by Meades and Moores (1989).
[2]Alexander (1988) uses Community Types for seral stages.

of vegetation classification systems: some are only for vegetation, while others are parts of terrain systems. A Canadian vegetation classification system (Strong *et al.* 1990) has been developed for use with ELS, but does not follow equivalent hierarchy to that indicated in Table 2.

Operational Groups

Stanek and Orloci (1987) defined eight silvicultural ecosystems, termed "operational groups," through an amalgamation of previously defined vegetation types (Orloci and Stanek 1979; Stanek 1980) using the concepts of Jones *et al.* (1983). The operational groups outlined for the Yukon pertain only to forested ecosystems which require the presence of a mature tree stratum for identification. Statistical evaluation (mostly cluster analysis or ordination) of vegetation and environmental factors disclosed the operational group indicators. The sequence for identifying an operational group as defined by Stanek and Orloci (1987) is: (1) select the appropriate tree category, (2) confirm with an understory species, (3) estimate the merchantability of the trees and (4) note the presence of permafrost within one meter of the soil surface. If spruce is predominant in the tree category, then site index is used to determine the final operational group.

The concepts of operational groups have merit, and the descriptions as presented offer some silviculturally useful ecological information about the site such as ecoregion, forest cover, site index, vegetation type, soil characteristics, and moisture regime. Once the operational group is determined, it is then possible to make interpretations covering the planning, harvesting, and regeneration of the stand. Some interpretations are presented in the operational group descriptions, and include such things as harvesting and reforestation options, most desired species per site, and stand tending possibilities.

More work is required to include all vegetation types in the operational groups and to bring ecologically equivalent vegetation types together. In the key presented by Stanek and Orloci (1987), spruce (white and black) and tamarack are included in the same initial group, yet the ecological amplitude of these species is quite different, and white spruce is the only species forming merchantable operational groups. However, merchantability is not a good criterion for partitioning a biological system. Other complications in using the procedure come with the indicated subordinate vegetation which is not exclusive to the tree group it is listed in, the absence of indicator species in some stands, and in the abundance of mixed and seral stands present in northern Canada. The stratification, however, can be useful to the field forester in many situations.

Forest Communities

The plant communities supporting tree cover in an ecoregion consisting mostly of a large valley with elevations ranging from 600 m to 2000 m above sea level were described by Oswald and Brown (1986). The community descriptions include general statements on the vegetation, common elevation for the community, characteristic and associated species, landform and soils, successional status, and productivity which includes basal area, volume, mean annual increment, and age data. The communities are similar to the vegetation types and phases of Stanek (1980), but do not incorporate the hierarchy of the vegetation types.

The forest communities include both seral and stable plant assemblages; thus the term "plant community" is used rather than "plant association" which is reserved for stable or "climax" species groups. They are primarily aimed for utilization with existing vegetation, but the stable association can be inferred once the successional (seral) sequences are elucidated and analyzed in relation to the substrate parameters (mostly soil texture, moisture regime, aspect, and elevation). The productivity class can be determined or estimated even if the trees are not present by examination of the physical site features and the subordinate vegetation (Oswald and Brown 1990). Interpretations can be made for various silvicultural practices.

Several communities were recognized, and other seral phases exist that may have one or two species at variance with those in a described community but have the same ecological equivalence. For making interpretations, it is useful to group the communities, on the basis of site and vegetation characteristics, into ecologically equivalent categories similar to the operational groups. For example, an abundance of *Arctostaphylos uva-ursi* indicates a dry, most often sandy, site of medium productivity which can support an overstory of *Picea glauca*, *Pinus contorta*, or *Populus tremuloides* within the ecoregion studied. Since the site characteristics are very similar, the silvicultural practices and interpretations

for managing these sites would also be very similar. However, because the tree species change, the operational groups as defined would not reveal the true similarity among these sites, so that a different definition must be devised. Perhaps a stratification for operational groups based on understory species would have more ecological significance than using the tree strata.

Discussion

The mobility of the human population brought about by technological advances (and improved access) is placing increasing demands on the forests, and other land resources, in what used to be the remote northern areas. These increased demands necessitate some holistic view of the resource field to even attempt to satisfy the various users. In consideration that there are 20,490,000 ha (9% of the total amount in Canada) of land area for timber production north of 60°N. Lat., containing wood volume of 700,000,000 m^3 (Honer and Bickerstaff 1985), it is justifiable to support a site classification program in this area to assist resource management. Much of the area has been covered by the Ecological Land Classification procedures at the ecoregion and ecodistrict levels, but very little by an intensive forest site classification.

Land in the north has relatively low forest productivity when compared to southern British Columbia, or much of the southern boreal forest, yet it has high values for the socio-economy of the north. The value lies in recreation, tourism, aesthetics, and wildlife habitat as well as wood production. Therefore, ecological factors other than those necessary for just growing merchantable trees must be included in any assessment of site analysis and classification.

The primary factors influencing tree productivity are climate, physiography, and soils, but these are interrelated and thus difficult to separate for assessment. The most important elements of climate are cold temperatures, short growing season, and limited precipitation, which are only partially compensated for by the long day length during the growing season. Daily temperatures can fluctuate over a wide range during a 24-h period; a 24-h range of 30°C or more may occur in the spring or fall.

Physiography plays a controlling role on the climate. The elevation differences brought about by the mountain ranges, allow for vast climatic differences. In general, tree growth is restricted to the lower slopes and valleys, but there are species differentiations from valley floor to tree line and between the northerly and southerly aspects. Cold air pooling and drainage arising from temperature inversions may restrict tree growth in some valleys. Precipitation at upper elevations, particularly the windward aspects, tends to be more plentiful than at lower elevations, and higher ranges get more than lower ranges.

The primary features of soils include texture and organic matter content, but alkalinity is a prominent factor in some places. Coarse-textured soils tend to be warmer but drier; soils with high organic matter content are often colder and wetter, but have a higher nutrient content-provided they are not supersaturated or frozen. The optimal balance is for moderately coarse-textured soils with a shallow but moving water table, such as some alluvial sites at lower elevations that lack permafrost. Such sites are few and have the greatest use allocation conflicts.

The most important attributes of a forest site classification system include provision for assessing forest productivity, and for extrapolating the site data from one site to another. Obviously, the amount of site energy put into tree growth is reduced by the amount put into the associated vegetation, lost to the atmosphere, or dissipated through some other means, and these must be accounted for in biomass assessments. Although classification is a site-specific event, in order for it to be useful, the information gained from analyses of one site must be extrapolatable to another site; this forms the basis of mapping. An important aspect of extrapolating information from one site to another is the amount of variability (range) permissible or allowed in the various site parameters. There are commonly fairly continuous gradients on mountain slopes of increasing soil depth, amount of moisture and nutrients received from up slope, and tree heights with decreasing elevation. The decision on amount of allowable variation in site parameters must be made before lines can be drawn separating these slopes into site types.

The data obtained by sampling a site provides only the basis for making interpretations. The data itself has little real significance unless it is compared to the data obtained from another site or to some presumed "normal" or standard. It is through this means that sites can be evaluated in terms of their potential for forestry, agriculture, recreation, wildlife habitat, trafficability, etc. In general, these land uses are evaluated for the site in its natural, unmodified state. From this, the best unmanaged use of the site can be determined. However, interpretations can go beyond this and indicate sites that would yield economic returns in agriculture or forestry from fertilization, thinning, and other stand tending. Some non-renewable resource interpretations, such as location and quantities of materials for road construction, trafficability, and erosion hazard, can be made. To make these interpretations, information from analyses by multidisciplinary resource teams and verification by historical trials and documented uses is required. Allowance must be made for changes in the socio-economics of the area.

Recommendations

- The entire area north of 60°N. Lat. should be covered with a broad scale classification and mapping at the Ecoregion and Ecodistrict levels. Much of this is already done (Senyk *et al.* 1988), but areas not covered need to be completed; contiguous maps should be assembled.

- Resource priorization must be done on the basis of the above surveys and maps. This could take the form of the Canada Land Inventory procedures, modified to meet the needs of northern Canada.

- Each resource group should concentrate initially on lands with the highest priority for the particular resource. More detailed classification and mapping should be performed within the broad scale framework.

- It would be useful to generate a GIS data base for maintaining up-to-date files as social and economic trends change, and to assist data access for making management decisions.

Forestry Group Concerns

- All forest lands, beginning with the most productive lands, should be classified at the Ecosite level. Analysis of the site potential as well as standing crop must be conducted. This will involve forest cover as well as vegetation classification and site descriptions.
- Vegetation successional patterns must be elucidated for each site type, and ecological equivalence determined even where the tree species or cover differ.
- Seral vegetation types should be grouped into ecologically equivalent groups through the use of physical site information.
- All necessary interpretations must be made on the basis of the physical and biological site data in concert with social needs. Factors to consider include tree species allocation, productivity assessments, trafficability, erosion hazard, silvicultural requirements, and conflicts with other resources.
- Harvesting schedules and procedures must be devised to be appropriate for the maintenance of economic tree removal, aesthetic appeal, sustainable growth, and avoidance of site degradation.
- Management strategies should be developed to encompass the physical and biological features of each site type, preserve or enhance the productivity, and promote economical utilization of the forest resource.
- Ecological reserves that encompass a wide variety of ecological conditions must be established. These must be large enough to ensure the integrity of the sites and biological systems; they must be preserved in perpetuity; they must be surveyed in detail, and their diversifications should be monitored over several centuries.

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Use of the biogeoclimatic ecosystem classification system in British Columbia

by A. MacKinnon,[1] D. Meidinger[1] and K. Klinka[2]

Abstract

Biogeoclimatic ecosystem classification (BEC) is a hierarchical system that organizes ecosystems at three levels of integration — local, regional and chronological. The system is used by silviculturists and range, recreation and wildlife managers in British Columbia. Based on the study of both vegetation and sites, the system reveals ecological potentialities and limitations of particular sites, and combined with the accumulation and widespread dissemination of ecological knowledge provides an ideal framework for integrated resource management. The ways in which the BEC system is adapted for, and used by, resource managers are described and demonstrated. Ongoing activities, including classification of seral ecosystems, quantification of soil moisture and nutrient regimes, identification of relationships between forest productivity and site quality, and provincial correlation of the six Regional classifications, are outlined.

Résumé

La classification biogéoclimatique des écosystèmes (CBE) est un système hiérarchique qui classe les écosystèmes selon trois niveaux : local, régional et chronologique. Les sylviculteurs et les gestionnaires des parcours, des loisirs et de la faune de la Colombie-Britannique utilisent le système hiérarchique. Fondé sur l'étude de la végétation et des sites, ce système révèle les possibilités et les limites écologiques de sites donnés et, lorsqu'il s'ajoute aux données écologiques accumulées et disséminées, il fournit un cadre idéal à une gestion intégrée des ressources. Le document décrit et montre comment le système de CBE a été adapté pour les gestionnaires des ressources et comment ces derniers l'utilisent. Il présente les grandes lignes des activités en cours, y compris la classification des stades sériaux des écosystèmes, la quantification du régime d'humidité du sol et du cycle des éléments nutritifs, l'identification des relations entre la productivité forestière et la qualité du site, et des corrélations provinciales des six classifications régionales.

Introduction

British Columbia's diverse climate and topography produce a large variety of forested ecosystems. The diversity is both dazzling and in some respects daunting: such a range of ecosystems seems designed to test the management skills of even the most experienced forester. It was primarily to bring some order to the bewildering array of landscapes that the ecological classification of our province's landbase has been undertaken. A number of ecological classifications (summarized in Pojar 1983) have been proposed for British Columbia. The classification dealt with in this paper is the biogeoclimatic ecosystem classification (BEC), the most widespread system used in our province today.

The aim of BEC is to classify the ecosystems of British Columbia in a way that will show their relationships (a) in form (likeness in vegetation or sites), (b) to climate, and (c) in time. The resulting classes are defined, named, and used:

- to identify and characterize the ecosystems that are the subject of research or management;
- to organize data for discovering relationships within and among the populations of ecosystems;
- to formulate generalizations from these relationships; and
- to apply these generalizations (Klinka *et al.* 1986).

BEC forms 'natural' taxonomic units (i.e., units based only on the characteristics of the ecosystems). These units may be grouped or divided to form interpretive units useful for particular purposes.

The goal of the ecosystem classification program in British Columbia is to assist in managing our landbase on an ecosystem-specific basis. This paper examines how resource managers in different fields (silviculture, range, recreation, and wildlife) have used the BEC system to help them manage their different resources, and how the BEC system can be used for integrated management in our province. The first two Sections briefly describe the BEC system, the way in which the sampling, analysis and synthesis of data has taken place, and the materials that have been produced to assist field personnel in identification of the delineated units. Then the use of the system by renewable resource managers is described. New directions aimed to expand the development of the system and its usefulness are outlined in the last four sections.

The Biogeoclimatic Ecosystem Classification System

BEC is a hierarchical system drawing on several of the European phytosociological and site classification traditions (Cajander 1926; Sukachev and Dylis 1964; Westhoff and van der Maarel 1980). In relation to North American systems, it is most similar to Daubenmire's habitat type system (e.g. Daubenmire 1968) in the western United States, and Ontario's (e.g., Hills 1952, 1976; Hills and Pierpoint 1960) and northern Michigan's (e.g., Barnes *et al.* 1982) site classification systems (Pojar *et al.* 1987). This Section provides a very simple description of the classification system; more detailed treatments of the system are available in Pojar *et al.* (1987, 1991) or Meidinger and MacKinnon (1989).

The BEC system organizes ecosystems at three levels of integration — local, regional and chronological (Figure 1). At the local level, vegetation and site classifications differentiate vegetation and site units. At the regional level, zonal (or climatic) classification differentiates climatically homogeneous biogeoclimatic units. At the chronological

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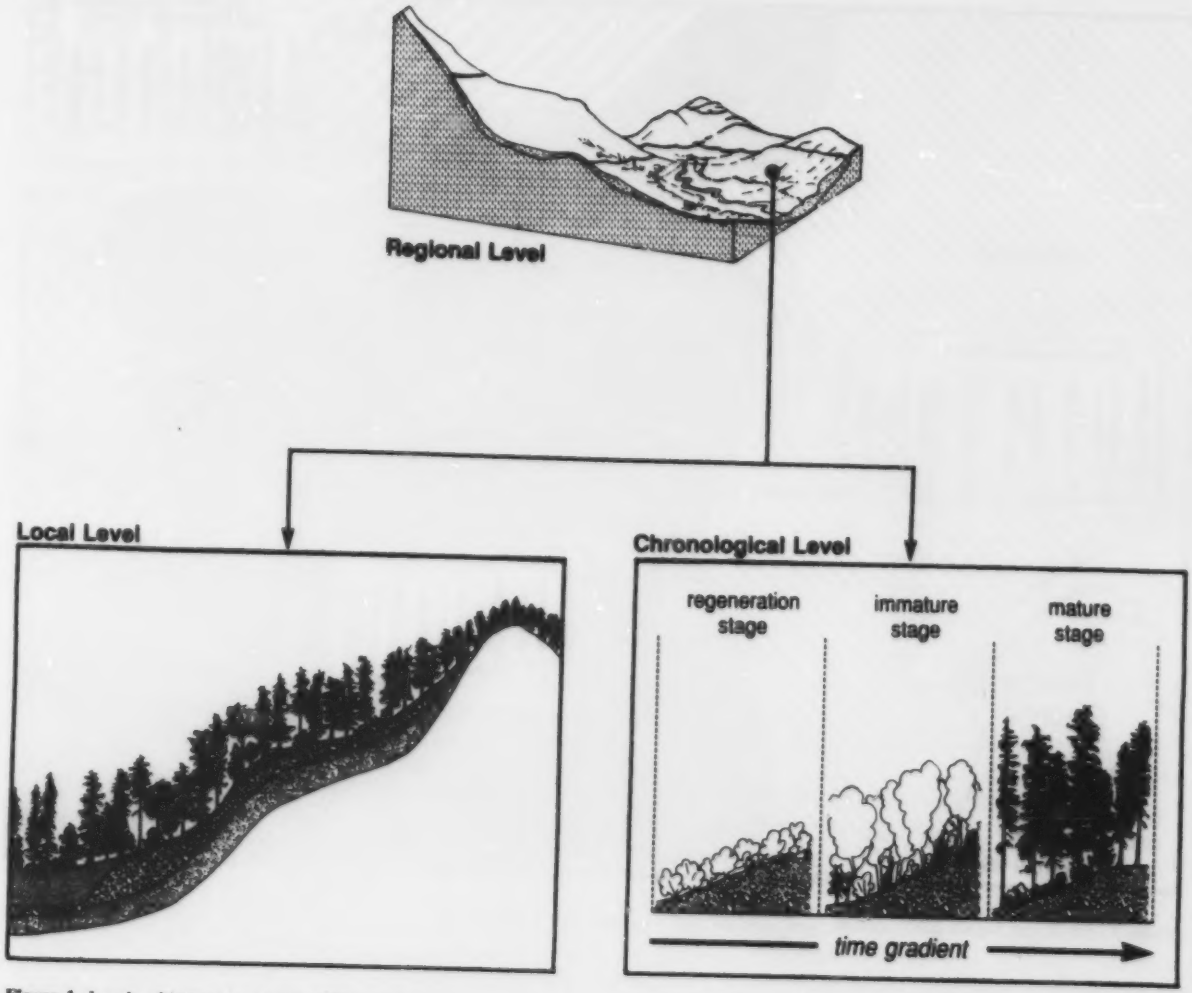

Figure 1. Levels of integration in the BEC system.

level, vegetation units are arranged into chronosequences that describe the vegetation succession for particular site units.

The most general units of the BEC system are the biogeoclimatic units. These represent areas of the landscape characterized by a uniform macroclimate, as inferred from the vegetation of zonal ecosystems. The basic and most commonly used unit at this level of the classification is the subzone. Subzones are fairly large geographic areas (Figure 2) characterized by a particular climatic climax (zonal) plant association on zonal sites (sites of intermediate moisture and nutrients).

For example, on these "average" sites in the moist (m), cool (k) Sub-Boreal Spruce (SBSmk) subzone (see Figure 2), the climax plant community has a canopy of subalpine fir (*Abies lasiocarpa*) and hybrid white spruce (*Picea glauca* × *engelmannii*), a shrub layer dominated by black huckleberry (*Vaccinium membranaceum*), and a herb layer characterized by bunchberry (*Cornus canadensis*). The zonal ecosystem of the wet, cool SBSwk subzone has more hybrid white spruce and subalpine fir in the canopy, black twinberry (*Lonicera involucrata*) in the shrub layer, and the excellent indicator of moist sites, oak fern (*Gymnocarpium dryopteris*) in the herb layer; and the very wet, cool SBSvk subzone features the wet site indicator devil's club (*Oplopanax horridus*) as the predominant shrub on its zonal sites.

Site classification organizes ecosystems into site units on the basis of shared stable environmental characteristics. The basic site unit is a site association, defined as all land areas with similar or equivalent physical properties which will produce similar plant communities at climax. A more climatically consistent site unit, the site series, is created by considering a site association within a particular biogeoclimatic subzone or variant (see Pojar *et al.* 1987 for specific definitions). This is the unit that land managers usually deal with. Site series may be divided into site types based on soil properties that often affect the management of the site. Figure 3 presents the most commonly occurring site series in one of the Sub-Boreal Spruce subzones.

Methodology

British Columbia's 30 million hectares are divided for management purposes into six Forest Regions (Figure 4). Ecosystem studies have been carried out primarily by research staff in the six Regions with some provincial

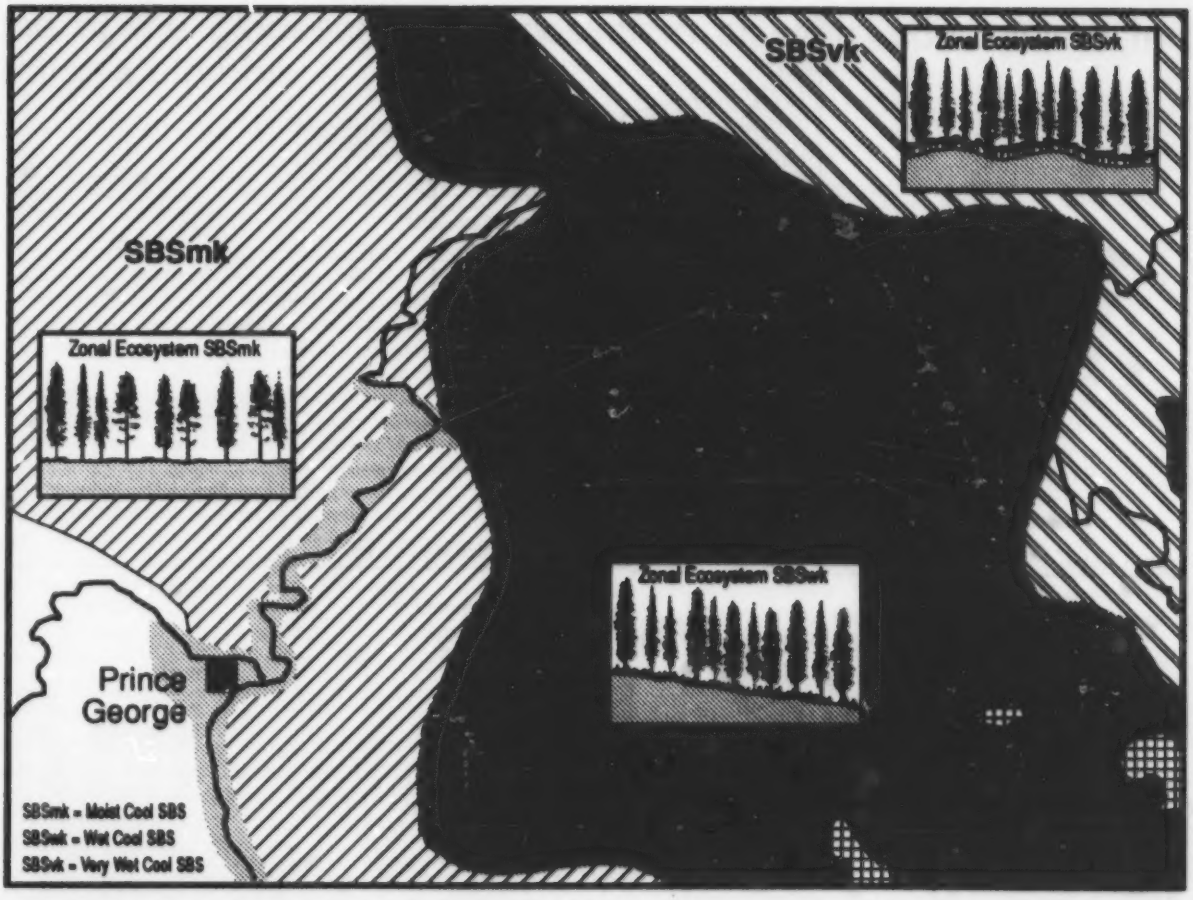

Figure 2. Sub-Boreal Spruce (SBS) subzones and zonal ecosystems around Prince George, B.C.

co-ordination. To date approximately 250 person-years have been invested in the ecological description of our province within the BEC system.

Maps of the biogeoclimatic units have been produced for over 90% of the province. The zones have recently been presented on a 1:2,000,000 scale provincial map (B.C. Ministry of Forests 1988). Subzones and variants are usually mapped at scales of 1:100,000 to 1:500,000 for operational and planning purposes; these are available as colour regional maps (e.g., Nuszdorfer *et al.* 1984; McLeod and Meidinger 1985; Pojar *et al.* 1988); or paper prints from mylars or computer databases. A digital 1:250,000 biogeoclimatic unit map for the entire province has recently been completed.

Characterization and description of site units has parallelled characterization and mapping of biogeoclimatic units. Site units are not generally mapped. Standard procedure is to map biogeoclimatic units, and have field personnel identify site units in the field using a variety of tools. However, certain high demand situations, usually requiring multiple use of forested Crown land, have merited the mapping of site units (e.g., Banner and Pojar 1987a; Clement *et al.* 1987; Klinka *et al.* 1980a, 1980b; Lindeburgh and Trowbridge 1985; Mitchell and Eremko 1987).

As a result of the field sampling (Walmsley *et al.* 1980; Luttmerding *et al.* 1990) and synthesis of vegetation, soil and site data (Meidinger *et al.* 1987), regional ecologists and pedologists differentiate vegetation and site units. Within a subzone or variant, from five to twelve site series are delineated, differing in soil moisture and nutrients, and other environmental characteristics. For convenience in site identification, these site series are usually displayed on an edatopic grid (Figure 5), a two-dimensional display of site series position on axes of moisture and nutrient regime. A variety of aids for site identification are provided in field guides for identification and interpretation of ecosystems. Guides to plant identification have also been produced for most of the province as part of the classification effort (Figure 6). Biogeoclimatic maps and field guides are available through Regional Ecology staff; some of the reports, guides, and maps available are listed in Table 1.

The field guides differ somewhat from one Region to the next, but they share some similar components. All begin by characterizing, in general terms, the biogeoclimatic units in the area covered by the guide. Aids to site identification are then presented by means of keys, edatopic grids, eco-amplitude (Figure 7) and toposequence diagrams (Figure 3). Usually, these aids are supplemented by descriptions of the soils, topography and vegetation for each site unit. The steps involved in site identification are summarized in Figure 8.

Management interpretations are also provided for site units. Interpretations are derived by the ecologists and pedologists

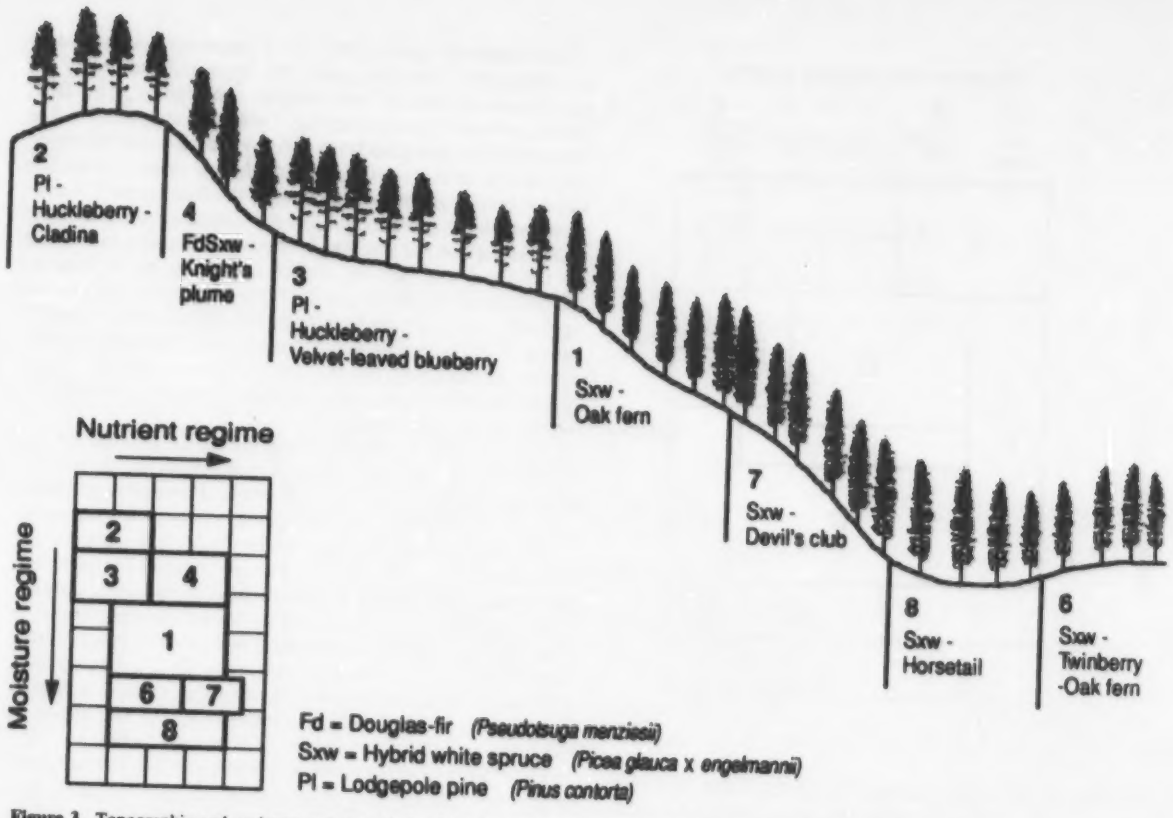

Figure 3. Topographic and moisture-nutrient relationships for the common site series in a wetter Sub-Boreal Spruce subzone.

Figure 4. Administrative Forest Regions in British Columbia. The cities indicated are Regional headquarters.

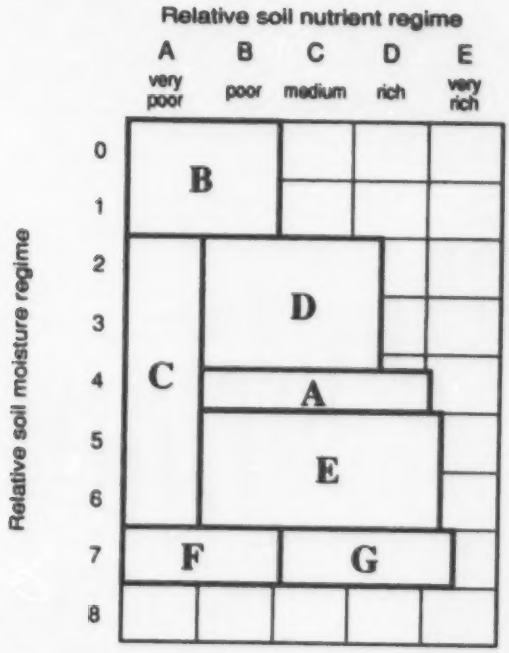

Figure 5. Edatopic grid displaying seven site units.

in consultation with other resource managers. These interpretations are intended to aid users in formulating the best possible ecosystem-specific prescriptions. All field guides contain silviculture interpretations. Most also contain interpretations for timber, wildlife, and range management.

Use of Biogeoclimatic Ecosystem Classification

Silviculture

From the requisite Pre-Harvest Silviculture Prescription, through site preparation, species and stock type selection, and stand tending activities, the BEC system is an integral part of silviculture in British Columbia.

A Pre-Harvest Silviculture Prescription must be conducted on each area to be harvested. The area is stratified into environmentally homogeneous blocks, which are then described in terms of soil, site and vegetation characteristics. The site series or types are identified for each block recognized in the setting, by means of the field guides. The silviculturist then turns to the interpretive section of the field guide for suggested treatment options.

Site treatment options take into account our understanding of ecosystem function and the accumulated body of experience in dealing with similar ecosystems. The BEC guides present "interpretations," not "prescriptions." The interpretations are guidelines used by the resource manager; they do not, in themselves, provide the site prescription. The interpretations are one component of the management framework which the professional forester considers when arriving at a prescription for the site, as they do not take into account all the local site factors. Other factors to be considered include the desired end product, the economics of various options, potential pest problems, etc. Much of the classification, site description and management prescription information is recorded on the computerized history record system, where it is available to assist resource managers in post-harvest decision making.

One example of the process is the office manual for the Vancouver Forest Region (Klinka *et al.* 1984) and the accompanying field guide (Green *et al.* 1984). These provide guidelines for site diagnosis and tree species selection for site series of the Vancouver Region. Appropriate tree species for reforestation are presented on an edatopic grid for each biogeoclimatic unit (Figure 9); this method of providing specific interpretations for each site unit ("direct interpretations") is the most commonly used method in BEC field guides. Principles used for selecting appropriate species for regenerating sites in southwestern British Columbia are outlined in Klinka and Feller (1984). Stocking standards for all site series in the province are presented in Anonymous (1990).

The effects of various site preparation techniques are most effectively documented on an ecosystem-specific basis. The work of Klinka *et al.* (1984) presents another approach to providing interpretations, as an aid to slashburning decision-making. Each block is rated on its sensitivity to fire on the basis of soil and site characteristics (Figure 10); this sort of interpretation is termed an "indirect interpretation", as it is not provided on a site unit basis. Similarly, Coates and Haeussler (1987) group site units with similar interpretations into "management units" in considering mechanical site preparation options in north-central British Columbia. Indirect interpretations for soil management in forestry are provided in Carr *et al.* (1991) and Lewis *et al.* (1991).

Another stand-tending consideration is the amount and timing of competition from non-crop vegetation that can be expected on a site. The study of vegetation response to certain site preparation treatments on particular sites is an area of very active research in the province today. An example of the sort of work being done can be found in Hamilton and Yearsley (1988), who examined the development of vegetation after clearcutting and site preparation on four

Table 1. Technical reports, field guides and maps for use in biogeoclimatic and site identification, for each Forest region

Forest Region	Technical reports/field guides/maps
Cariboo	Annas and Coupé (1979); Forest Sciences Section, Cariboo Forest Region (1987, 1989); Roberts (1984); Steen and Roberts (1988)
Kamloops	Lloyd *et al.* (1990); Mitchell and Green (1981)
Nelson	Comeau *et al.* (1982); Utzig *et al.* (1986)
Prince George	DeLong (1988); DeLong and McLeod (1987); DeLong *et al.* (1985, 1986, 1987a, b, c); MacKinnon and McLeod (1984, 1986); MacKinnon *et al.* (1990); McLeod and Meidinger (1985); Meidinger *et al.* (1984, 1988)
Prince Rupert	Banner and Pojar (1987b); Banner *et al.* (1983, 1988, 1989, 1990); Clement *et al.* (1990); Haeussler *et al.* (1984, 1985); Houseknecht *et al.* (1987); Lewis *et al.* (1986); Pojar *et al.* (1983, 1984, 1988); Standish *et al.* (1987); Trowbridge *et al.* (1983); Yole *et al.* (1989)
Vancouver	Green *et al.* (1984); Klinka *et al.* (1984); Nuszdorfer (1990a, b); Nuszdorfer *et al.* (1984); Pojar *et al.* (1988)

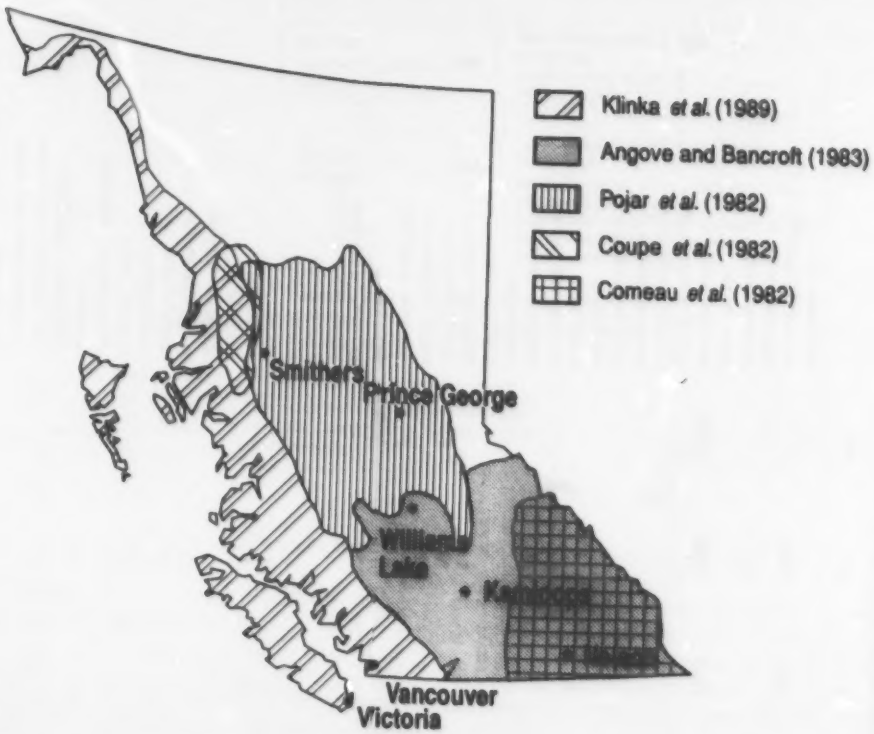

Figure 6. Areas of British Columbia covered by Forest Service plant identification or indicator guides.

different site units in the SBSwk1 variant. Information such as the total volume of vegetation (m^3/m^2) on the different site units over the first twelve years after logging (Figure 11) can then be used to derive ecologically sound, ecosystem-specific silvicultural interpretations.

The work of various researchers (e.g. Ketcheson *et al.* 1985; Hamilton and Yearsley 1988) on development of key competitive species and species complexes after specific site preparation activities feeds important autecological information into the classification. Their information, however, gathered in hindsight, is based on sites harvested up to 15 years ago, and some key information (e.g. burn impact) may be sparse or non-existent. Much of the monitoring work going on now is intended to follow vegetation development from harvesting onwards, and should provide a less variable (and so more dependable) basis for predicting secondary succession on an ecosystem-specific basis.

Fertilization decision-making is also dependent on site characteristics, in particular soil nutrient regime. Carter and Klinka (1988) propose site-specific guidelines for coastal Douglas-fir fertilization. They list the most responsive fertilizer treatments, and probable three-year growth responses, for spaced immature Douglas-fir in southern coastal British Columbia. These recommendations and predicted responses are given for each site association in the Very Dry and Dry Maritime Coastal Western Hemlock subzones.

Ecosystem-specific planning can be extended to stand-specific planning for management of woodlots. Examples of this are provided in Green *et al.* (1987) and Courtin *et al.* (1989) for sites on Lasqueti and Saltspring Islands, respectively; both islands form part of the Gulf Islands, in the Strait of Georgia between Vancouver Island and the mainland. In Green *et al.* (1987), 16.2 ha of Lasqueti Island are characterized and described within the BEC system. Ecosystems are grouped into "working groups" (groups of ecosystems within one subcompartment to be managed under the same silvicultural regime for a particular management objective), and these working groups are then mapped (Figure 12). The authors generate various summaries and maps to assist in planning and operations on small-scale forestry holdings.

Classification data that describe the environmental components of a variety of ecosystems often yield sufficient information to characterize some aspects of the autecology of species. This information was synthesized for tree species in Krajina (1969), Krajina *et al.* (1982) and Pojar (1985), among others. Three reports of particular note to silviculturists characterize the most productive Douglas-fir ecosystems (Klinka *et al.* 1981; Klinka and Carter 1980) and Engelmann spruce ecosystems (Klinka *et al.* 1982) in southwestern British Columbia. In these reports the sites producing the best growth of Douglas-fir and Engelmann spruce are identified and described in terms of their soil, site and vegetation characteristics. Silvicultural interpretations are suggested for these most productive ecosystems.

BEC field guides provide guidelines for establishing a new crop on a site while taking into account other resource uses (e.g., wildlife, range, recreation). They also provide information on possible hazards to the stand after establishment. Stand susceptibility to vegetation competition, microclimatic stress (e.g., drought, frost), flooding, and pest (insect and disease) attack can often be predicted on a site unit basis.

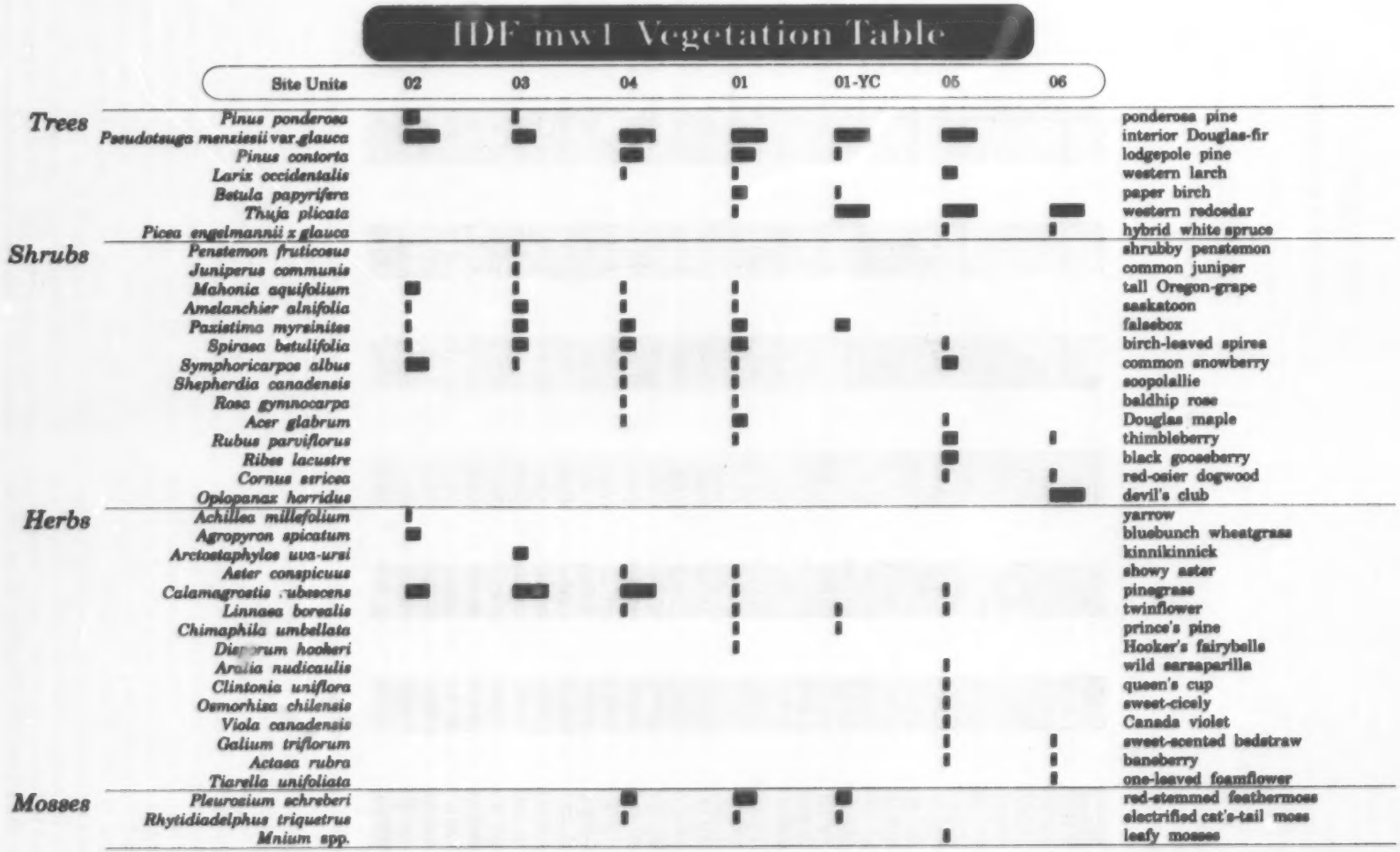

Figure 7. Vegetation table for site series in the Shuswap Moist Warm Interior Douglas-fir variant (IDFmwl) (from Lloyd *et al.* 1990). Larger bars indicate higher "prominence values" (which incorporate species frequency and mean cover).

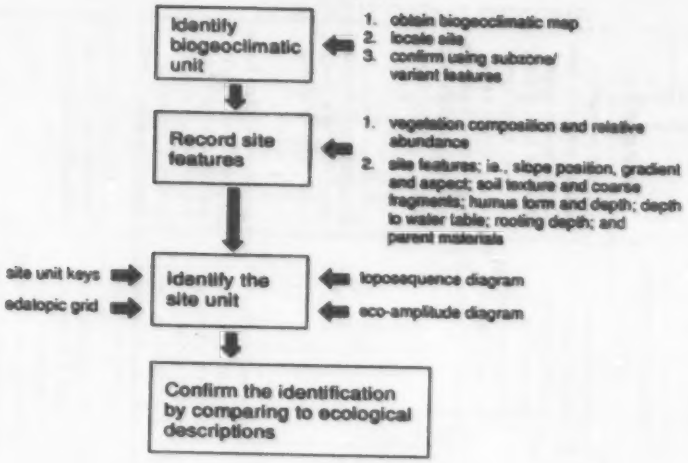
Identify biogeoclimatic unit
1. obtain biogeoclimatic map
2. locate site
3. confirm using subzone/ variant features
Record site features
1. vegetation composition and relative abundance
2. site features; ie., slope position, gradient and aspect; soil texture and coarse fragments; humus form and depth; depth to water table; rooting depth; and parent materials
site unit keys
edaiopic grid
Identify the site unit
toposequence diagram
eco-amplitude diagram
Confirm the identification by comparing to ecological descriptions

Figure 8. Steps involved in site identification.

The silviculturist is able to avoid some problems, and is aware of the potential for others to occur.

Range

Another area where the BEC system could prove useful is in range management, particularly in integrated management involving forestry and range concerns on Crown land.

For broad-scale range planning, biogeoclimatic units are useful; Wikeem (1983), for example, uses them to present information on grazing to define research needs. As ranching is very important in the Cariboo Forest Region, their field guide (Forest Sciences Section, Cariboo Forest Region 1989) provides range interpretations (Table 2). These interpretations are a first attempt at accommodating range interests in the BEC system. However attempts to predict the results of range management activities on a site unit basis require data on the response of that site unit to manipulation. Because of this, authors such as Pitt (1982, 1984) point out that until the classification system includes information such as the "strong relationships between forage production and forest cover types," that "specific resource management problems are clarified best with specific inventory and data collection programs."

There are no inherent limitations to using BEC for range management decisions. Lewis (1982) suggests that, "with minor modification, [BEC] can form the basis of [a] geographic information system" on which to base range management activities. If this classification system is to be used for range interpretations, however, more research must be directed towards understanding the structure and dynamics of plant communities, and their response to manipulation.

A new research initiative in the Ministry of Forests is intended to develop an interpretive ecosystem classification, probably based on BEC, for rangeland management.

Recreation

Ecosystem classification and mapping may assist in integrating recreation into multiple-use management. By identifying the ability of different site units to support recreational activity, the designation of land for recreational use can be compared to the designation of the same land for other activities, and optimal combinations can be found.

BEC is also used to assist recreation managers in determining the capability of an area to support recreation, and the level of development necessary to meet the recreation objectives for an area. Inselberg *et al.* (1982), for example, identify and map site series and site types within MacMillan Park (also known as "Cathedral Grove") on Vancouver Island. Recreational interpretations for each unit are prepared on the basis of:

- dominance of large coniferous trees (many visitors come to enjoy the old-growth stands of Douglas-fir, western hemlock and western redcedar, with trees taller than 70 m on good sites);
- canopy cover;
- shrub cover;
- species diversity;
- trafficability (based on soil moisture regime and slope); and
- need to regenerate Douglas-fir.

The 1:2,500 scale map of the 90-ha park represents an intensive mapping procedure which may not be feasible for planning development over a larger landbase. In this case, however, it provides the information required for ecologically based recreation management of a heavily used park.

Parks Canada has commissioned biophysical (ecological) mapping in nearly all of its management areas, as an aid to park planning and interpretation. The BEC role in the interpretation of our environment to recreationists has not been well explored.

Wildlife Habitat

As with range or recreation management, combinations of vegetation and site units are appropriate as wildlife habitat management units. Use of BEC site units for habitat management, however, will require gathering of additional information on vegetation in various stages of secondary succession, community structure as it relates to animal needs, and response of site units to manipulation and the effect this has on wildlife carrying capacity of the unit. In addition, supplemental information on physical characteristics of the land-

Table 2. Range interpretations for site series of the SBSdw2 variant (from Forest Sciences Section, Cariboo Forest Region 1989)

SITE UNIT	SIGNIFICANT NATIVE FORAGE	CARRYING CAPACITY AND SEASON	RESPONSE TO GRAZING	RESPONSE TO TIMBER MANAGEMENT	FORAGE SEEDING SPECIES[1]	COMMENTS
SBSdw2/01: Fd - Sx - Pinegrass	pinegrass, showy aster, heart-leaved arnica, rough-leaved ricegrass, prickly rose, birch-leaved spirea, saskatoon	3-4 ha/AUM early June to late September	heavy grazing of pinegrass in July may reduce its vigour in subsequent year	forage production usually increases within 1 to 3 years after logging for a period of 4 to 8 years; forage production after logging may be reduced by shrub growth; seeding forage species on exposed mineral soil within first year after logging will usually increase forage production	principal species; orchardgrass (Kay or Chinook), timothy, alsike clover, bromegrass minor species: white clover, creeping red fescue	pinegrass palatability declines after mid June and nutritional value after mid July; mature deciduous types have greatest forage value; range livestock use concentrated on disturbed areas
SBSdw2/02: Fd - Juniper - Feathermoss	very sparse	extremely low	n/a	forage potential may increase slightly after logging	n/a	occupies small localized areas with little forage value; may be used as resting areas
SBSdw2/03: Pl - Pinegrass - Feathermoss	usually sparse; pinegrass, (prickly rose), birch-leaved spirea, showy aster	unlogged - very low logged - 4 to 7 ha/AUM mid June to mid September	heavy grazing of pinegrass in July may reduce its vigor in subsequent year	forage production usually increase significantly after logging; seeding domestic species within first year after logging may increase production	principal species: orchardgrass (Kay or Chinook), timothy, alsike, clover, bromegrass minor species; white clover, creeping red fescue	forage production limited by cool north aspects and often dense tree layer; grazing potential generally limited to logged or burned areas
SBSdw2/04: Pl - Kinnikinnick - Feathermoss	pinegrass, showy aster, prickly rose, saskatoon	4 - 5 ha/AUM early June to late September	heavy grazing of pinegrass in July may reduce its vigour in subsequent year	forage potential may increase slightly after logging	crested wheatgrass (omit if broadcast), orchardgrass (Kay), bromegrass, creeping red fescue, white clover or dryland alfalfa	livestock use low; use limited by steep slopes

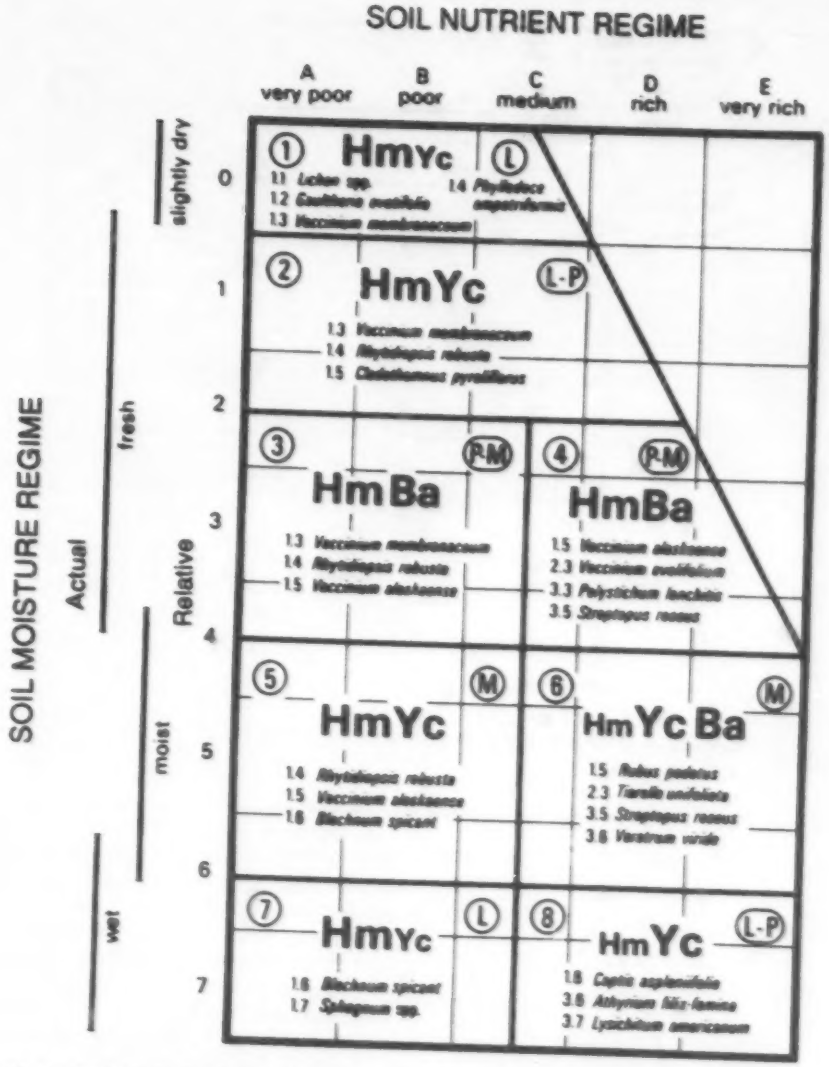

Figure 9. Tree species selection guidelines for the Mountain Hemlock (MH) "a" subzone: Hm = mountain hemlock (*Tsuga mertensiana*), Yc = yellow-cedar (*Chamaecyparis nootkatensis*), Ba = Pacific silver fir (*Abies amabilis*). The scientific names represent indicator species groups characteristic of those moisture and nutrient regimes. The circled letters represent growth class symbols: G = good, M = medium, P = poor, and L = low. (from Klinka *et al.* 1984).

scape (e.g., slope, aspect, elevation) and climatic characteristics not included as BEC criteria (e.g., snowpack depth and duration) may be required. The potential use of ecological classification systems in wildlife management in British Columbia was reviewed by Stevenson (1982).

Biogeoclimatic subzones are used in all habitat mapping by the Wildlife Branch, B.C. Ministry of Environment (MOE), as a climatic framework for plant community distribution. A series of 1:500,000 maps and legends entitled "Ecoregions and biogeoclimatic units" for each MOE management area within British Columbia was completed in autumn 1988. Subzones are stratified into "important habitats" (e.g., estuary, floodplain, old-growth forests), and important wildlife species in each habitat are identified. This information provided the basis for the wildlife summaries for each zone presented in Meidinger and Pojar (1991). Other maps are produced by Wildlife Branch at scales of 1:250,000 to 1:50,000; on these maps, wildlife habitat units may be mapped within the biogeoclimatic unit boundaries.

Lea (1986) describes an approach used by the MOE for describing vegetation in Wells Gray provincial park. In this work the "vegetation landscapes" ("plant habitats that have the potential to support similar communities of vegetation through various stages of successions") are described within biogeoclimatic units; these "vegetation landscapes" are similar in concept to site units in BEC. He describes successional communities occurring on each vegetation landscape, and evaluates each vegetation landscape for potential forage and cover value for several featured wildlife species (hare, moose, mule deer, woodland caribou, mountain goat and grizzly bear).

The Ministry of Forests also uses biogeoclimatic units to represent regional climates for wildlife management purposes. In *Handbook for Timber and Mule Deer Management*

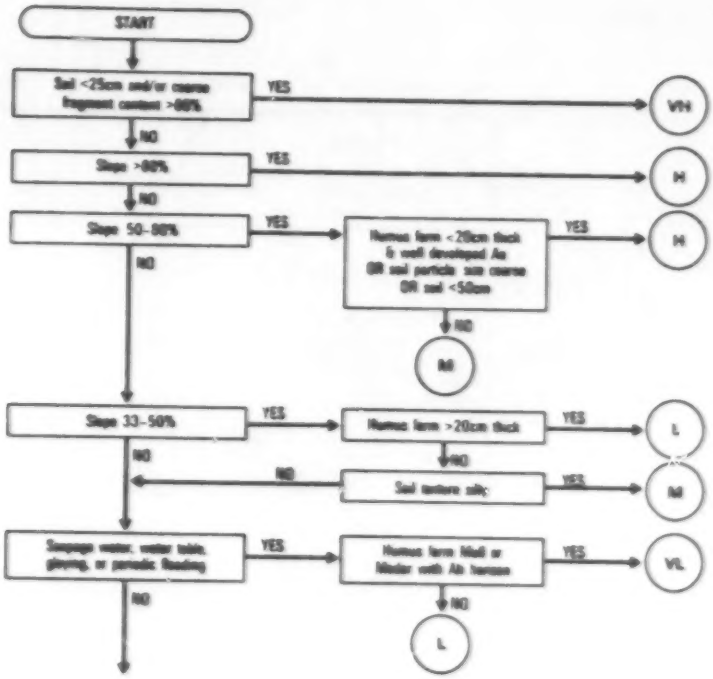

Figure 10. A portion of a key to identification of site sensitivity to prescribed fire. VH = very high, H = high, M = medium, L = low VL = very low (from Klinka *et al.* 1984).

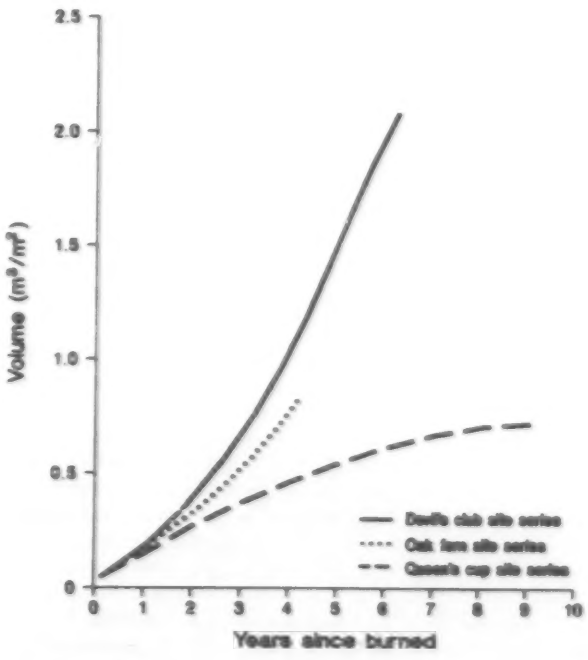

Figure 11. Volume of herbs, shrubs and deciduous trees in early-seral (10 years since burned) ecosystems in the SBSwk subzone. The Devil's club, Oak fern and Queen's cup ecosystems represent wetter than average, average, and drier than average site units, respectively, in this subzone. (after Hamilton and Yearsley 1988).

Co-ordination on Winter Ranges in the Cariboo Forest Region, Armleder and his colleagues (1986) use the Cariboo Region field guide (Forest Sciences Section, Cariboo Forest Region 1989) to delineate the "snowpack zones" of the Cariboo Forest Region. These snowpack zones are then used as a broad planning tool for integrated forestry-wildlife use of Crown lands in the Cariboo Region. Biogeoclimatic units were also used by Nyberg *et al.* (1990) in defining snowpack zones for deer and elk habitat management on British Columbia's south coast.

Researchers in the Prince Rupert Forest Region (Banner and Pojar 1985; Banner *et al.* 1985) classified and mapped coastal grizzly bear habitat in the the lower Kimsquit Valley on the central mainland coast of British Columbia (Figure 13). In the 5000 ha study area, the joint Ministry of Forests-Ministry of the Environment study distinguished seven forested site series and two non-forested site series (avalanche tracks and wetlands). Forested units were classed in eight physiognomic successional stages, and also divided into nineteen "variations" based on present species composition (seral association). Map units were pre-typed from 1:20,000 colour aerial photographs, and ground-checked. The vegetation units formed the primary components of the map units; soils and landform units formed the secondary components. This mapping provided the framework on which grizzly habitat studies, including intensive monitoring of radio-collared bears, could be overlaid. Digitizing the maps makes it a relatively simple matter to produce derivative maps for wildlife (or other) interpretations. This application is being further developed in the Khutzeymateen Valley Grizzly Bear Study (Hamilton and Nagy 1990; Clement 1990).

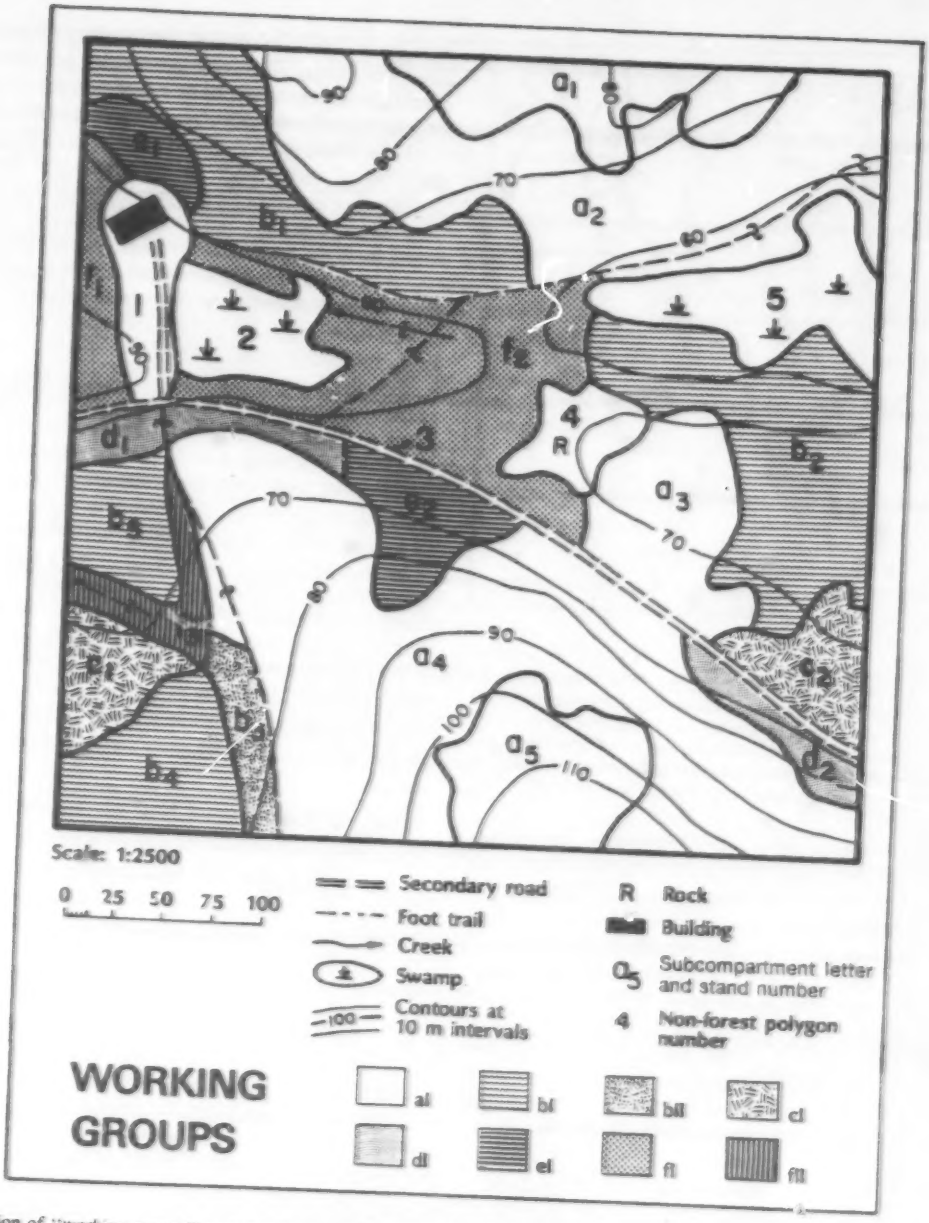

Figure 12. Distribution of "working groups" over a study area on Lasqueti Island (from Green *et al.* 1987).

A similar co-operative study (Clement *et al.* 1987; Clement 1987; Cichowski and Banner 1990) is being conducted between the Ministries of Forests and Environment, to digitally map winter habitat of the Tweedsmuir-Entiako and Itcha-Ilgatchuz woodland caribou herds of central British Columbia. In conjunction with digitized forest cover maps indicating forest cover type, age and site class, it becomes possible to generate overlays and summaries of, for example, timber volume by caribou habitat type. In combination with data on caribou movements and habitat use, this mapping is being used to define caribou management zones that will guide future forestry development in the area (Cichowski and Banner 1990).

Interpretive units for black-tailed deer and Roosevelt elk habitat management, called "understory types," were derived from BEC site units on Vancouver Island and the southern mainland (Nyberg and Janz 1990). These units, named for dominant understory species, are the basis for interpretations of forage and cover productivity and responses to silvicultural practices (Figure 14).

New Directions

Correlation

The biogeoclimatic ecosystem classification of British Columbia was undertaken relatively independently in each of the six Forest Regions. These Regional data and classifications have been pooled to produce a correlated provincial classification. The data were re-analyzed and synthesized with the result that some units are being merged and the relationships between similar ecosystems in different Forest Regions

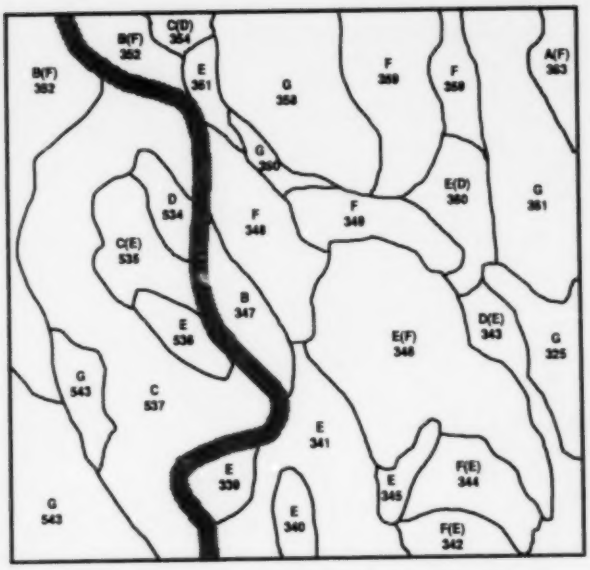

Figure 13. A portion of a map of ecosystems of the Kimsquit River Valley on the central mainland coast of British Columbia. Letters refer to successional stages; polygon numbers refer to a characteristic combination of site series and landform-soil unit. For example, polygons C-537 (cottonwood-alder-salmonberry-devil's club, mature seral) and E-536 (riverbar scrub, pioneer seral) represent different seres of the same site series. These different seres have different value to grizzly bears (after Banner and Pojar 1985).

is being clearly demonstrated. Interpretations for the correlated units are also being prepared on a provincial basis. The intent is to produce a non-redundant ecosystem classification and a consistent set of recommended forest management practices for each unit. The results of this provincial correlation are starting to be published provincially (B.C. Ministry of Forests 1988; Banner *et al.* 1990; Meidinger and Pojar 1991; Klinka *et al.* 1991) and regionally (Meidinger *et al.* 1988; DeLong *et al.* 1990; Lloyd *et al.* 1990; MacKinnon *et al.* 1990). Other technical publications (e.g., zonal monographs) and field guides will become available over the next few years.

Vegetation Dynamics

Just as a wildlife or range manager wants to know the forage production to be expected on a site after a particular disturbance, so a silvicultural manager wants to be able to predict the vegetation development on a site following various disturbances. Conard (1984) stated:

> The classification of seral vegetation in British Columbia ... could be an extremely useful tool for predicting the development of competing vegetation following disturbance on forest sites, for identifying sites where similar problems are likely to develop, and for planning vegetation management treatments.

In consequence, recent work has been directed towards the study of disturbed ecosystems and vegetation dynamics and the development of site-specific vegetation chronosequences.

The classification of early- and mid-seral plant communities follows a similar approach to that applied for the late-seral (near-climax or climax) communities. Regardless of successional status, all plant communities are classified into a hierarchy of vegetation units which are then related to site units to form site-specific chronosequences (Pojar *et al.* 1987).

Klinka *et al.* (1985) and Hamilton (1988) proposed that the type of disturbance or treatment and the structural-developmental stages form a framework for stratifying seral vegetation units. By means of the framework, each site association recognized in the BEC system can be characterized by a sequence of plant communities likely to follow certain types of disturbance (Figure 15).

This information can be used by various resource managers in slightly different ways. For example, on a particular site a silviculturist may want to know what type of vegetation is likely to develop following various site preparation treatments (e.g., mechanical, prescribed fire) in order to best avoid vegetation competition with planted seedlings. Wildlife or range managers may be interested in encouraging treatments which direct succession towards seres with good forage value, or a rapid recovery to good hiding or snow intercept qualities.

Some commonly occurring early-seral plant communities following fire disturbance in southwestern British Columbia were classified by Klinka *et al.* (1985). In the same area, McGee (1988) classified early-seral plant communities following various intensities of mechanical disturbance on B.C. Hydro transmission right-of-ways. DeLong (1988) described mid-seral vegetation units in one subzone of the Boreal White and Black Spruce Zone in northeastern British Columbia.

Characterization of Soil Moisture and Nutrient Regimes

Site or its quality has been defined as the sum total of all environmental factors affecting the plant community of an ecosystem (Spurr and Barnes 1980). As different combinations of environmental factors may have a similar effect on plants, those factors that have a more direct influence are most useful for characterization of site. The BEC system uses light and heat (i.e., climatic regime expressed by biogeoclimatic subzone or variant), soil moisture regime (SMR), and soil nutrient regime (SNR) to characterize site quality. Sites with similar climatic, soil moisture, and soil nutrient characteristics (i.e., site associations) have similar quality, and, as a result similar vegetation and productivity potentials.

Until recently, classification of SMRs and SNRs has been carried out by means of relative scales within biogeoclimatic units. For example, a mesic site (a site judged to have "average" moisture for a subzone or variant) in a wet climate would actually be wetter than a mesic site in a drier climate, but both would be called "mesic" as they are sites with similar site and soil physical properties. As management impacts on vegetation and soil depend essentially on actual rather than relative soil moisture and nutrient regimes, quantitative characterization and effective field identification of SMRs and SNRs are of essential importance to the BEC system.

Some progress has been made towards characterization of actual soil moisture and nutrient regimes. Klinka *et al.* (1984) used the occurrence and duration of phases of water use, complemented by the ratio between actual and potential evapotranspiration (AET:PET), and the occurrence and depth of the water table, to differentiate actual SMRs. In the field,

Biogeoclimatic Units	SNR[1]	Soil Moisture Regime (Potential Hygrotope)[2]							
		0	1	2	3	4	5	6	7
CDFa[3] (CDFmm[4])	A	Lichen - Moss	California Brome		Salal - Huckleberry		Moss		Sphagnum - Hardhack
	B		Ocean-spray - Tall Oregon-grape		Salal - Dull Oregon-grape		Sword Fern		Skunk Cabbage
CDFb (CWHxm1)	A	Lichen - Salal			Salal - Huckleberry		Moss		Sphagnum - Hardhack
	B	Ocean-spray - Tall Oregon-grape			Salal - Dull Oregon-grape		Sword Fern / Salmonberry[5]		Skunk Cabbage
CWHa1 (CWHxm2)	A	Lichen - Salal	Salal - Huckleberry			Huckleberry - Moss	Deer Fern		Sphagnum - Hardhack
	B		Moss - Dull Oregon-grape				Sword Fern / Salmonberry[5]		Skunk Cabbage
CWHa2 (CWHdm)	A	Lichen - Prince's Pine	Salal - Huckleberry		Huckleberry - Moss		Deer Fern		Sphagnum - Hardhack
	B		Moss - Dull Oregon-grape				Sword Fern / Salmonberry[5]		Skunk Cabbage
CWHb1 (CWHvm1)	A	Lichen - Salal	Salal - Huckleberry		Huckleberry - Moss		Deer Fern		Sphagnum - Deer Fern
	B				Moss		Sword Fern / Salmonberry[5]		Skunk Cabbage
CWHb2 (CWHvm2)	A	Lichen - Moss	Moss		Huckleberry - Moss		Deer Fern	Sphagnum - Deer Fern	
	B						Rosy Twistedstalk - Five-leaved Bramble	Skunk Cabbage	
CWHb3 (CWHmm1)	A	Lichen - Salal	Salal - Huckleberry		Huckleberry - Moss		Deer Fern		Sphagnum - Deer Fern
	B		Salal - Dull Oregon-grape		Moss		Sword Fern / Salmonberry[5]		Skunk Cabbage
CWHb4 (CWHmm2)	A	Lichen - Moss	Huckleberry - Moss				Deer Fern		Sphagnum - Deer Fern
	B		Huckleberry - Dull Oregon-grape				Rosy Twistedstalk - Five-leaved Bramble		Skunk Cabbage
CWHb5 (CWHms1)	A	Lichen - Falsebox	Moss - Kinnikinnick		Huckleberry - Moss		Deer Fern		Sphagnum - Deer Fern
	B				Huckleberry - Rosy Twistedstalk		Oak Fern		Skunk Cabbage
CWHc1 (CWHds1)	A	Lichen - Prince's Pine	Moss - Falsebox				Moss		Sphagnum
	B	Ocean Spray - Tall Oregon-grape	Moss - Dull Oregon-grape				Oak Fern		Skunk Cabbage
CWHd1 (CWHvh1)	A	Lichen - Salal	Salal - Huckleberry				Deer Fern		Sphagnum
	B			Moss			Sword Fern		Skunk Cabbage
MHa	A	Lichen - Pink Mountain-heather	Huckleberry - Moss				Deer Fern	Sphagnum - Deer Fern	
	B			Huckleberry - Rosy Twistedstalk			Rosy Twistedstalk - Five-leaved Bramble	Skunk Cabbage	
MHb	A	Lichen - Pink Mountain-heather	Black Huckleberry - White-flowered Rhododendron		Huckleberry - Moss		Deer Fern		Sphagnum - Deer Fern
	B				Huckleberry - Rosy Twistedstalk		Rosy Twistedstalk - Five-leaved Bramble		Indian Hellebore
MHp	A	Lichen - Pink Mountain-heather	Mountain-heathers		Black Huckleberry - White-flowered Rhododendron		Sitka Valerian - Arnica		Indian Hellebore
	B								
	C								
	D								
	E								

1. Soil nutrient regime: A = very poor, B = poor, C = medium, D = rich, E = very rich
2. Soil moisture regime (Potential hygrotope): 0 = very xeric, 1 = xeric, 2 = subxeric, 3 = submesic, 4 = mesic, 5 = subhygric, 6 = hygric, 7 = subhydric
3. Codes for biogeoclimatic units from Green *et al.* 1984 .
4. Revised codes for biogeoclimatic units,1988 (D. Meidinger, personal communication).
5. The Salmonberry (Devil's Club) type replaces the Sword Fern type on sites with a high water table.

Figure 14. The lichen-salal understory type: position on the biogeoclimatic unit-edatope matrix. Potential forage values are: for deer, moderate in winter, low in spring and summer; for elk, low year-round.

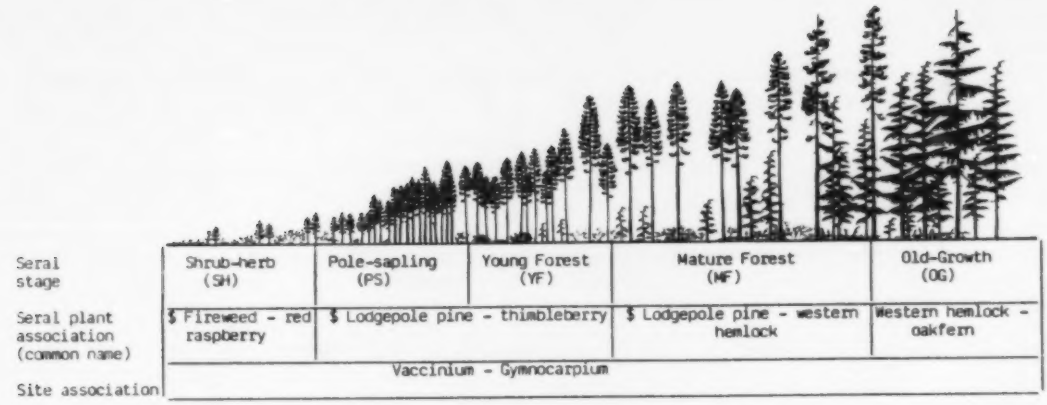

Figure 15. Classification of seral stage and seral plant associations in a site association (after Hamilton 1988).

actual SMRs with water surplus are identified according to the depth of growing-season groundwater table. Other SMRs are identified by using a key to relative SMR. The key (Figure 16) considers soil depth, texture, coarse fragment content, organic matter content, gleyed horizons, and external inputs and removals of soil water due to position in the landscape (i.e., soil water-holding capacity) to arrive at a relative SMR class. The relative SMR is then related to an appropriate actual SMR by means of the edatopic grids (see Figure 9).

Courtin *et al.* (1985) quantified SNRs in coastal British Columbia by using four soil parameters as differentiae. They delineated seven soil groups, correlated these groups with the floristic composition and forest productivity of the associated forest communities, and assigned the groups to five SNR classes. Further studies on the characterization of

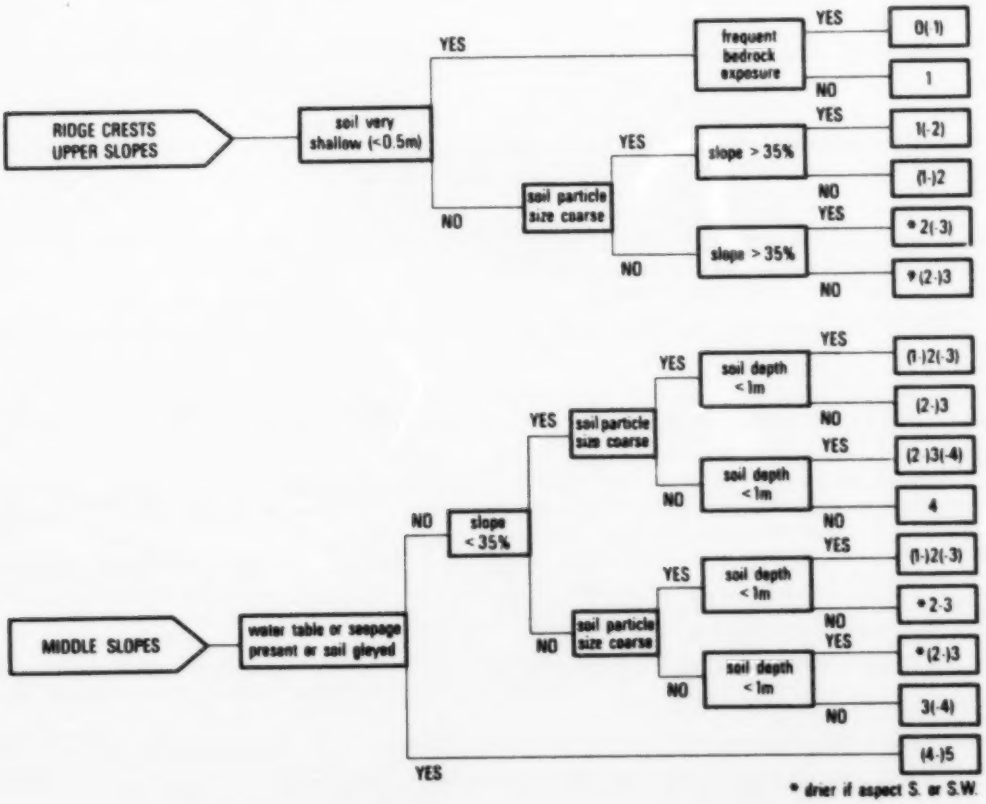

Figure 16. A portion of a key to identification of actual moisture regime. 0-5 refer to the moisture classes (hygrotopes) on an edatopic grid; 0 = very dry, 5 = "moist" (from Klinka *et al.* 1984).

SNRs using mineralizable nitrogen as the key factor have been carried out by Kabzems and Klinka (1987a, b). Actual SNRs are identified in the field according to a key which considers the humus form, soil depth, texture, coarse fragment content, organic matter content, minerology, and possible external nutrient inputs (Figure 17).

Relationships between Site Quality and Forest Productivity

Classification of a forest into site units provides a suitable framework for both ecosystem-specific management and study of relationships between site quality and forest productivity, because the factors used to characterize site quality (i.e., climate, soil moisture regime, and soil nutrient regime) may also be used as independent variables in simple synoptic models describing growth performance of trees. These relationships were examined recently for disturbed, immature, coastal Douglas-fir ecosystems in the Very Dry and the Dry Maritime Coastal Western Hemlock subzones by Klinka and Carter (1988). They examined variations in Douglas-fir site index (m/50 years) in relation to understory vegetation (expressed as factor scores of principal components analysis), vegetation and site units of the BEC system, climatic soil moisture and soil nutrient measures (expressed as categorical or continuous variables) (Table 3).

Of the eight regression models developed, understory vegetation alone, either expressed as the factor scores of principal components analysis or vegetation units, had a weak relationship with site index. The models based on continuous site variables had poorer performance than those based on categorical site variables (site units or their formative elements). Testing on an independent data set showed that only the models based on categorical site variables continued to have a good relationship with site index.

These results support the use of site units (or climatic, soil moisture, and soil nutrient regimes) in evaluation of site quality. The models using continuous variables require further improvements and, probably, selection of a more accurate productivity index than site index. Similar studies are carried out by graduate students at the Faculty of Forestry, University of British Columbia, for black cottonwood, lodgepole pine, Sitka spruce, and western hemlock, with some being expanded to modelling height growth based on stem analysis.

Old-growth Project

The government of British Columbia has recently embarked on a process to develop a strategy for management of our province's old-growth forests. Much of the information we have regarding old-growth forests in British Columbia comes from the data collected during sampling conducted by the ecosystem classification program. Definitions for our various old-growth forests are being derived within the BEC framework. Investigations into the feasibility of developing new management practices (e.g. Hopwood 1991) have been conducted for specific zones and ecosystems. In addition, inventories of how much old growth we have, and what we need in protected status, are being conducted on a biogeoclimatic unit basis.

Summary

Each tree species will grow and behave in ways that depend on the sites and ecosystems in which it grows. Similarly, different forest ecosystems will respond to different treat-

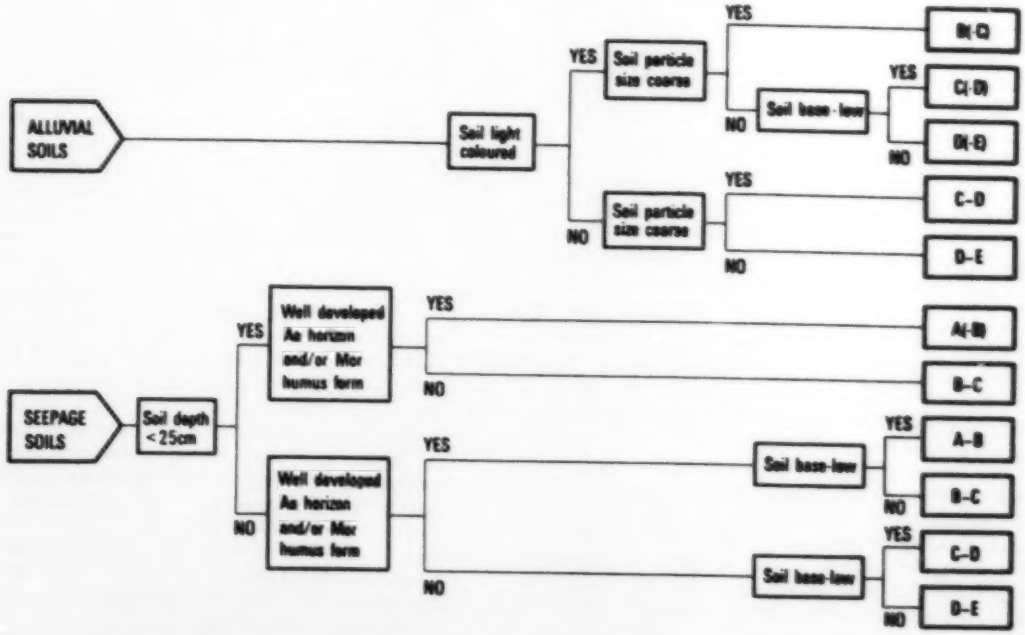

Figure 17. A portion of a key to identification of actual nutrient regime. A-E refer to the nutrient classes (trophotopes) on an edatopic grid; A = very poor, E = very rich (from Klinka *et al.* 1984).

Table 3. Models for regression of Douglas-fir site index on understory vegetation and envivornment factors used to characterize site quality (from Klinka and Carter 1988)

[1] SI = 29.1 + 1.23(PCA1)[1] + 0.39(PCA2) + 1.85(PCA3)		
Adjusted R^2 = 0.320	F = 16.4	S.E. = 4.1
[2] SI = 34.6 − 11.7(VUA)[2] − 7.4(VUB) − 5.1(VUC) − 1.4(VUD) − 2.2(VUE)		
Adjusted R^2 = 0.384	F = 13.1	S.E. = 4.0
[3] SI = 34.3 − 13.8(SU1)[3] − 7.7(SU2) − 2.6(SU3) + 1.3(SU4)		
Adjusted R^2 = 0.803	F = 100.1	S.E. = 2.2
[4] SI = 34.6 − 14.0(VD)[4] − 7.7(MD) − 3.0(SD) − 0.01(F)		
Adjusted R^2 = 0.744	F = 71.3	S.E. = 2.6
[5] SI = 35.5 − 13.2(VP)[5] − 9.7(P) − 4.0(M) − 0.6(R)		
Adjusted R^2 = 0.657	F = 47.4	S.E. = 3.0
[6] SI = 35.5 − 7.0(VD) − 1.4(MD) + 0.1(SD) + 3.1(F) − 9.4(VP) − 7.4(P) − 4.9(M) − 1.5(R)		
Adjusted R^2 = 0.845	F = 67.1	S.E. = 2.0
[7] SI = 26.6 − .36(E_tMay)[6] + .12(E_tJune) + .91(LFminN) + 3.36(LMminN)		
Adjusted R^2 = 0.715	F = 33.6	S.E. = 2.9
[8] SI = 21.7 − .046(WD) + 3.65(LMminN)		
Adjusted R^2 = 0.627	F = 43.0	S.E. = 3.2

[1]PCA1 through PCA3 are factor scores from the first three axis derived from principal components analysis (PCA) of all diagnostic species.
[2]VUA through VUE are dummy variables representing vegetation units A through E.
[3]SU1 through SU4 are dummy variables representing site units 1 through 4.
[4]SMR where VD — very dry; MD — moderately dry; SD — slightly dry; and F — fresh.
[5]SNR where VP — poor; P — poor; M — medium; and, R — rich.
[6]E_t(May) and E_t(June) — actual evapotranspiration during May and June; LFminN and LMminN — natural log of mineralizable N in the forest floor and surface 30 cm of the mineral soil, respectively.

ments in different ways, depending largely on the characteristics of the ecosystem. What is then required is a classification of forest ecosystems into biologically-equivalent site units. This has been accomplished by the BEC system. The system assists forest managers in selection of the most suitable crop tree species and silvicultural regimes for each site unit and management objective. Management planning and operation are simplified by combining many individual ecosystems into fewer environmentally characterized classes.

Owing to the pioneering work of Dr. V.J. Krajina, the ecology of British Columbia forests is well understood and is being used to manage the sustained development of the forest resource. The biogeoclimatic ecosystem classification — an integral part in this process — has become an accepted term after some ten years of systematic training of the government and industrial field staff in identification and interpretation of ecosystems. Such acceptance was not gained by government decree but by the virtues of the BEC system: it has made ecology understandable and applicable. This effort has resulted in increased ecological awareness and considerable improvement in forest management in British Columbia.

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